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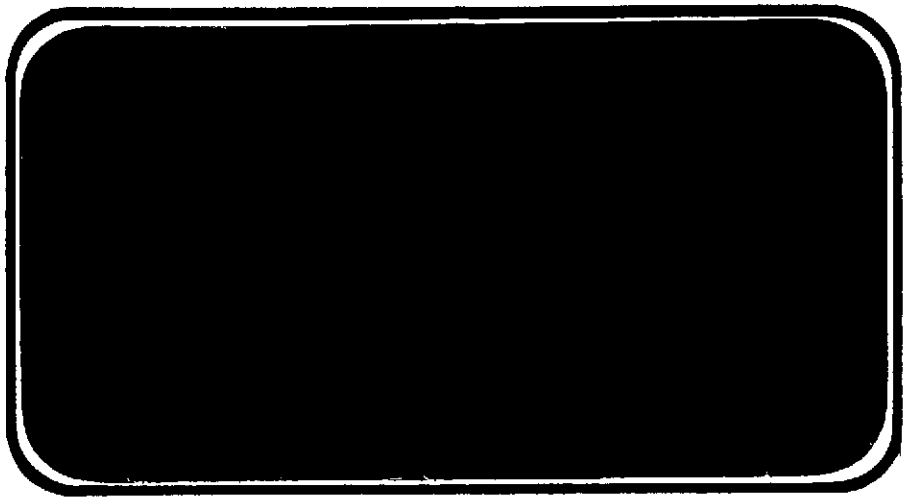

SPACE SHUTTLE

AEROTHERMODYNAMIC DATA REPORT

JOHNSON SPACE CENTER

HOUSTON, TEXAS

DATA MANagement services

SPACE DIVISION CHRYSLER CORPORATION

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RESULTS OF OIL FLOW VISUALIZATION TESTS OF AN 0.010-SCALE MODEL (52-OT) OF THE SPACE SHUTTLE ORBITER-TANK MATED AND ORBITER CONFIGURATIONS IN THE AEDC VKF TUNNEL B (IA17B)

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Prepared under NASA Contract Number NAS9-13247

By

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for

Engineering Analysis Division

Johnson Space Center
National Aeronautics and Space Administration
Houston, Texas

WIND TUNNEL TEST SPECIFICS:

Test Number: AEDC VKF-B VA422
NASA Series Number: IA17B
Model Number: 52-OT
Test Dates: 18 through 19 March 1974
Occupancy Hours: 8

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ABSTRACT

An 0.010-scale model of the Space Shuttle (Orbiter-tank mated and Orbiter configurations) was tested in the AEDC VKF Tunnel B during March 1974 to investigate aerodynamic flow patterns. The tests utilized oil flow techniques to visualize the flow patterns. Tunnel free stream Mach number was 7.95 and nominal unit Reynolds number was 3.7 million per foot. Model angle of attack was varied from -5° through 10° and angle of sideslip was 0° and 2°. Photographs of resulting oil flow patterns are presented.

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TABLE OF CONTENTS

INDEX OF MODEL FIGURES

INDEX OF DATA FIGURES

INDEX OF DATA FIGURES (Concluded)

NOMENCLATURE
General

SYMBOL	SADSAC SYMBOL	DEFINITION
a		speed of sound; m/sec, ft/sec
C_p	CP	pressure coefficient; $(p_l - p_\infty)/q$
M	MACH	Mach number; V/a
p		pressure; N/m^2, psf
q	Q(NSM) Q(PSF)	dynamic pressure; $1/2\rho V^2$, N/m^2, psf
RN/L	RN/L	unit Reynolds number; per m, per ft
V		velocity; m/sec, ft/sec
α	ALPHA	angle of attack, degrees
β	BETA	angle of sideslip, degrees
ψ	PSI	angle of yaw, degrees
ϕ	PHI	angle of roll, degrees
ρ		mass density; kg/m^3, $slugs/ft^3$
		Reference & C.G. Definitions
A_b		base area; m^2, ft^2
b	BREF	wing span or reference span; m, ft
c.g.		center of gravity
ℓ_{REF} $\bar{c}$	LREF	reference length or wing mean aerodynamic chord; m, ft
S	SREF	wing area or reference area; m^2, ft^2
	MRP	moment reference point
	XMRP	moment reference point on X axis
	YMRP	moment reference point on Y axis
	ZMRP	moment reference point on Z axis

SUBSCRIPTS

b	base
l	local
s	static conditions
t	total conditions
∞	free stream

CONFIGURATIONS INVESTIGATED

Model 52-O is an 0.010-scale representation of the Space Shuttle Configuration 3 Orbiter, built to the lines depicted in Rockwell Dwg. VL70-000139B. It is of all steel construction to withstand the enviroment of hypersonic tunnels. Adjustable control surfaces can be provided by means of interchangeable brackets, however, all control surfaces were at nominal settings for this test.

The 52-T model is an 0.010-scale representation of the Vehicle 5 External Tank with protrusions and attach fittings as shown on Rockwell Dwg. VL78-000062. The tank model is also of all steel construction.

The following configuration notation was used:

$$\text{Orbiter} = B_{19}\ C_{7}\ E_{23}\ F_{5}\ M_{4}\ N_{8}\ N_{24}\ R_{5}\ V_{7}\ W_{107}$$

$$\text{ET} = T_{20}\ AT_{16}\ AT_{17}\ AT_{18}\ AT_{20}\ PT_{9}\ PT_{10}\ PT_{11}\ PT_{12}\ FL_{3}\ FL_{4}$$

A complete description of configuration dimensions is given in Table II and Figure 2.

TESTING TECHNIQUES

The oil used for these tests was composed of a silicone oil base (trade named Dow Corning Fluid), a Titanium Dioxide pigment, and Oleic acid (to enhance suspension). Different combinations of two viscosities (10 and 100 centistokes) of the oil base were mixed with varying quantities of pigment and a few drops of acid until satisfactory results were obtained. When oil viscosity is too low, the oil blows off of the model and oil patterns change during retraction of the model from the test section. If the viscosity is too high the oil dries out before the flow pattern can be satisfactorily established. The model was painted with flat black high temperature enamel-paint. Oil was applied by spraying it evenly over the entire model surface.

The test procedure was to paint the model (touch up bad spots in between runs), apply the oil, and inject the model into the tunnel with the model set at the attitude for the run. After the flow pattern had established and photos were taken the model was retracted and close-up photos of the oil pattern were taken. On mated vehicle configurations the Orbiter was detached from the ET in order to photograph the lower surface of the Orbiter and the upper surface of the ET.

TEST FACILITY DESCRIPTION

Arnold Engineering Development Center (AEDC) is an Air Force facility located in Tullahoma, Tenn. The tunnel used, Tunnel B, is in the von Karmon Facility. Engineering and other technical operations in this tunnel are conducted by contractor personnel of ARO, Inc.

Tunnel B is a continuous, closed circuit, variable density wind tunnel with an axisymmetric contoured nozzle and a 50-inch diameter test section. The tunnel can be operated at nominal Mach numbers of 6 or 8 at stagnation pressures from 20 to 300 and 50 to 900 psia, respectively, and at stagnation temperatures of up to 1350° R. The model may be injected into the tunnel for a test run and then retracted for model cooling or model changes without interrupting the tunnel flow.

TEST I. - TEST SUMMARY

Run Number	Configuration	α (deg)	β (deg)	ϕ (deg)	Comments
1	Orbiter + ET	0	0	0	Oil too heavy
2	Orbiter + ET	0	0	0	Oil too heavy
3	Orbiter + ET	0	0	0	Oil too heavy
4	Orbiter + ET	0	0	0	good
5	Orbiter + ET	-5	0	0	good
6	Orbiter + ET	0	2	0	good
7	Orbiter + ET	-5	2	0	good
8	Orbiter + ET	-5	2	0	Check run
9	Orbiter + ET	5	0	180	good
10	Orbiter	0	0	0	good
11	Orbiter	-5	0	0	good
12	Orbiter	5	0	180	good
13	Orbiter	10	0	180	good

Tunnel freestream conditions:

Mach number = 7.95
Total pressure = 240 psia
Total temperature = 790 °F
Unit Reynolds number = 3.7×10^6 per foot

TABLE II. MODEL DIMENSIONAL DATA

MODEL COMPONENT: BODY - B_{19}

GENERAL DESCRIPTION: Fuselage, configuration 3,

NOTE: Identical to B_{17} except forebody.

MODEL SCALE: 0.010 .

DRAWING NUMBER VL70-000139B

DIMENSION:	FULL SCALE	MODEL SCALE
Length	1290.3	12.903
Max Width	267.6	2.676
Max Depth	244.5	2.445
Fineness Ratio	4.822	4.822
Area - Ft^2		
Max Cross-Sectional	386.67	0.039
Planform		
Wetted		
Base		

TABLE II (CONT'D)

MODEL COMPONENT: CANOPY - C_7

GENERAL DESCRIPTION: Configuration 3

MODEL SCALE: 0.010

DRAWING NUMBER VL70-000139

DIMENSION:	FULL SCALE	MODEL SCALE
Length (X_o=433 to X_o= 578), In.	145.00	1.450
Max Width		
Max Depth		
Fineness Ratio		
Area		
Max Cross-Sectional		
Planform		
Wetted		
Base		

TABLE II (CONT'D)

MODEL COMPONENT: ELEVON - E_{23}

GENERAL DESCRIPTION: Configuration 3 per W_{107}

MODEL SCALE: 0.010

DRAWING NUMBER: VL70-000139B

DIMENSIONS:

	FULL-SCALE	MODEL SCALE
Area - Ft^2	205.52	0.0206
Span (equivalent), In.	353.34	3.533
Inb'd equivalent chord, In.	114.78	1.148
Outb'd equivalent chord, In.	55.00	0.550
Ratio movable surface chord/ total surface chord		
At Inb'd equiv. chord	0.208	0.208
At Outb'd equiv. chord	0.400	0.400
Sweep Back Angles, degrees		
Leading Edge	0.00	0.00
Tailing Edge	- 10.24	-10.24
Hingeline	0.00	0.00
Area Moment (Product of area and $\bar{c}$) (Normal to hinge line), Ft^3	1548.07	0.0015

TABLE II (CONT'D)

MODEL COMPONENT: BODY FLAP - F_5

GENERAL DESCRIPTION: Configuration 3

MODEL SCALE: 0.010

DRAWING NUMBER VL70-000139

DIMENSION:	FULL SCALE	MODEL SCALE
Length , In.	84.70	0.847
Max Width , In.	267.6	2.676
Max Depth		
Fineness Ratio		
Area - Ft^2		
Max Cross-Sectional		
Planform	142.5	1.425
Wetted		
Base	38.096	0.0038

TABLE II (CONT'D)

MODEL COMPONENT: OMS POD - M_4

GENERAL DESCRIPTION: Configuration 3

NOTE: M_4 identical to M_3, except intersection to fuselage.

MODEL SCALE: 0.010.

DRAWING NUMBER VL70-000139

DIMENSION:	FULL SCALE	MODEL SCALE
Length, In.	346.0	3.460
Max Width, In.	108.0	1.080
Max Depth, In.	113.0	1.130
Fineness Ratio		
Area		
Max Cross-Sectional		
Planform		
Wetted		
Base		

TABLE II (CONT'D)

MODEL COMPONENT: NOZZLES - N 8

GENERAL DESCRIPTION: Basic OMS nozzle of configuration 2A configuration

Intersection of nozzle exit plane and nozzle centerline at X_o = 1570.75, Y_o = ± 99.25, Z_o = 507.25.

MODEL SCALE: 0.010

DRAWING NUMBER: VL70-008306, -000089B, SS-A00092

DIMENSIONS:	FULL SCALE	MODEL SCALE
MACH NO.		
Length - In.		
Gimbal Point to Exit Plane		
Throat to Exit Plane		
Diameter - In.		
Exit	50.00	0.500
Throat	N/A	N/A
Inlet	28.00	0.280
Area - ft^2		
Exit	13.635	0.136
Throat		
Gimbal Point (Station) - In.		
X	1518.00	15.180
Y	± 88.0	± 0.880
Z	492.0	4.920
Lower Nozzles		
X		
Y		
Z		
Null Position - Deg.		
Pitch	$15^{\circ}49'$	$15^{\circ}49'$
Yaw	± $12^{\circ}17'$	$\pm 12^{\circ}17'$
Lower Nozzle		
Pitch		
Yaw		

TABLE II (CON'T)

MODEL COMPONENT: MPS NOZZLES - N_{24}

GENERAL DESCRIPTION: Configuration 140A/B orbiter MPS nozzles.

MODEL SCALE: 0.010 MODEL DRAWING: SS-A0147, Rel. 12

DRAWING NUMBER: VL70-005030A, -000140A

DIMENSIONS:	FULL SCALE	MODEL SCALE
MACH NO.		
Length - In.		
Gimbal Point to Exit Plane	157.0	1.570
Throat to Exit Plane	99.2	0.992
Diameter - In.		
Exit	91.00	0.910
Throat		
Inlet		
Area - ft^2		
Exit	45.166	0.452
Throat		
Gimbal Point (Station) - In.		
Upper Nozzle		
X	1445.00	14.450
Y	0	0
Z	443.0	4.430
Lower Nozzles		
X	1468.170	14.682
Y	± 53.00	± 0.530
Z	342.640	3.426
Null Position - Deg.		
Upper Nozzle		
Pitch	16	16
Yaw	0	0
Lower Nozzle		
Pitch	10	10
Yaw	3.5	3.5

TABLE II (CONT'D)

MODEL COMPONENT: RUDDER - R_5

GENERAL DESCRIPTION: Configuration 140C orbiter rudder (Identical to configuration 140A/B rudder).

MODEL SCALE: 0.010

DRAWING NUMBER: VL70-000146B, -000095

DIMENSIONS:

	FULL-SCALE	MODEL SCALE
Area - Ft^2	100.15	0.0100
Span (equivalent), In.	201.00	2.010
Inb'd equivalent chord, In.	91.585	0.916
Outb'd equivalent chord , In.	50.833	0.508
Ratio movable surface chord/ total surface chord		
At Inb'd equiv. chord	0.400	0.400
At Outb'd equiv. chord	0.400	0.400
Sweep Back Angles, degrees		
Leading Edge	34.83	34.83
Tailing Edge	26.25	26.25
Hingeline	34.83	34.83
Area Moment (Product of area & $\bar{c}$), ft^3	610.92	0.0006
Mean Aerodynamic Chord, In.	73.2	0.732

TABLE II (CONT'D)

MODEL COMPONENT: VERTICAL - V_7

GENERAL DESCRIPTION: Centerline vertical tail, doublewedge airfoil with rounded leading edge.

MODEL SCALE: 0.010

DRAWING NUMBER: VL70-000139

DIMENSIONS:	FULL SCALE	MODEL SCALE
TOTAL DATA		
Area (Theo) - Ft^2		
Planform	425.92	0.0426
Span (Theo) - In.	315.72	3.157
Aspect Ratio	1.675	1.675
Rate of Taper	0.507	0.507
Taper Ratio	0.404	0.404
Sweep-Back Angles, Degrees.		
Leading Edge	45.000	45.000
Trailing Edge	26.249	26.249
0.25 Element Line	41.130	41.130
Chords:		
Root (Theo) WP	268.50	2.685
Tip (Theo) WP	108.47	1.084
MAC	199.81	1.998
Fus. Sta. of .25 MAC	1463.50	14.635
W.P. of .25 MAC	635.522	6.355
B.L. of .25 MAC	0.00	0.00
Airfoil Section		
Leading Wedge Angle - Deg.	10.00	10.00
Trailing Wedge Angle - Deg.	14.920	14.920
Leading Edge Radius	2.00	0.020
Void Area	13.17	0.0013
Blanketed Area	0.0	0.0

TABLE II (CONC'L)

MODEL COMPONENT: WING-W_{107}

GENERAL DESCRIPTION: Configuration 3

NOTE: Same as W except cuff airfoil and incidence angle

MODEL SCALE: 0.010

TEST NO.

DWG. NO. VL70-000139B

DIMENSIONS:	FULL-SCALE	MODEL SCALE
TOTAL DATA		
Area (Theo.) Ft^2	2690.00	0.2690
Planform		
Span (Theo In.	936.68	9.367
Aspect Ratio	2.265	2.265
Rate of Taper	1.177	1.177
Taper Ratio	0.200	0.200
Dihedral Angle, degrees	3.500	3.500
Incidence Angle, degrees	0.500	0.500
Aerodynamic Twist, degrees	3.000	3.000
Sweep Back Angles, degrees		
Leading Edge	45.000	45.000
Trailing Edge	- 10.024	- 10.024
0.25 Element Line	35.209	35.209
Chords:		
Root (Theo) B.P.0.0.	689.24	6.892
Tip, (Theo) B.P.	137.85	1.379
MAC	474.81	4.748
Fus. Sta. of .25 MAC	1136.89	11.369
W.P. of .25 MAC	299.20	2.992
B.L. of .25 MAC	182.13	1.821
EXPOSED DATA		
Area (Theo) Ft^2	1752.29	0.1752
Span, (Theo) In. BP108	720.68	7.207
Aspect Ratio	2.058	2.058
Taper Ratio	2.451	2.451
Chords		
Root BP108	562.40	5.624
Tip 1.00 $\frac{b}{2}$	137.85	1.379
MAC	393.03	3.930
Fus. Sta. of .25 MAC	1185.31	11.853
W.P. of .25 MAC	300.20	3.002
B.L. of .25 MAC	251.76	2.518
Airfoil Section (Rockwell Mod NASA) XXXX-64		
Root $\frac{b}{2}$ =	0.100	0.100
Tip $\frac{b}{2}$ =	0.120	0.120
Data for (1) of (2) Sides		
Leading Edge Cuff Planform Area Ft^2	0.1	
Leading Edge Intersects Fus M. L. @ Sta	118.333	0.0118
Leading Edge Intersects Wing @ Sta	500.00	5.000
	1083.4	10.834

TABLE II (CONT'D)

MODEL COMPONENT: TANK - T_{20}

GENERAL DESCRIPTION: External oxygen-hydrogen tank.

MODEL SCALE: 0.010 .

DRAWING NUMBER VL72-000131, VL78-000062

DIMENSION:	FULL SCALE	MODEL SCALE
Length (Nose @ X_T = 328.92), In.	1846.905	18.469
Max Width (@ X_T = 975.675), In.	333.2	3.332
Max Depth Major Depth, In.	330.2	3.302
Fineness Ratio	5.657	5.657
Area - Ft^2		
Max Cross-Sectional (@ X_T=975.675)	605.534	0.0606
Planform Major Cross Section	594.679	0.0595
Wetted WP of Tank Centerline (Z_T), In.	400.00	0.040
Base (On 330.2 Dia.)	594.679	0.0595

TABLE II. (CONT'D)

MODEL COMPONENT: ATTACH STRUCTURE - AT_{16}

GENERAL DESCRIPTION: Forward orbiter/ET attach structure (2 member structure)

MODEL SCALE: 0.010 MODEL DRAWING: SS-A00117

DRAWING NO.: VL78-000062B, SK-H-4011

DIMENSIONS:	MEMBER		FULL SCALE	MODEL SCALE
	#1	X_o	394.38	3.944
		Y_o	0.0	0.0
		Z_o	LWR ML	LWR ML
		X_T	1131.0	11.310
		Y_T	46.8	0.468
		Z_T	561.298	5.613
	#2	X_o	394.38	3.944
		Y_o	0.0	0.0
		Z_o	LWR ML	LWR ML
		X_T	1131.0	11.31 -
		Y_T	- 46.8	-0.468
		Z_T	561.298	5.613
Diameter, In.	#1			
	#2			

TABLE II (CONT'D)

MODEL COMPONENT: ATTACH STRUCTURE - AT_{17}

GENERAL DESCRIPTION: Left rear orbiter/ET attach structure (2 member structure).

MODEL SCALE: 0.010 MODEL DRAWING NO.: SS-A00117

DRAWING NO.: VL78-000062B, SK-H-4013

DIMENSIONS:	MEMBER		FULL SCALE	MODEL SCALE
	#1	X_o	1317.00	13.170
		Y_o	- 96.5	- 0.965
		Z_o	267.5	2.675
		X_T	2058.0	20.580
		Y_T	-125.827	- 1.258
		Z_T	515.5	5.155
	#2	X_o	1317.00	13.170
		Y_o	- 96.5	- 0.965
		Z_o	267.5	2.675
		X_T	2058.0	20.850
		Y_T	-125.827	--1.258
		Z_T	515.5	5.155
Diameter, In.	#1 (F.S.)		11.5	0.115
	#2 (F.S.)		15.5	0.155

TABLE II (CONT'D)

MODEL COMPONENT: ATTACH STRUCTURE - AT_{18}

GENERAL DESCRIPTION: Right rear orbiter/ET attach structure (3 member structure)

MODEL SCALE: 0.010 MODEL DRAWING: SS-A00117

DRAWING NO.: VL78-000062B, SK-H-4013

DIMENSIONS:	MEMBER		FULL SCALE	MODEL SCALE
	#1	X_o	1317.00	13.170
		Y_o	96.5	0.965
		Z_o	267.5	2.675
		X_T	1872.00	18.720
		Y_T	125.827	1.258
		Z_T	515.5	5.155
	#2	X_o	1317.0	13.170
		Y_o	96.5	0.965
		Z_o	267.5	2.675
		X_T	2058.0	20.580
		Y_T	125.827	1.258
		Z_T	515.5	5.155
	#3	X_o	1317.0	13.170
		Y_o	54.40	0.544
		Z_o	19.30	0.193
		X_T	2058.0	20.580
		Y_T	2.5	0.025
		Z_T	567.6	5.676
Diameter of members, In.:	#1		15.5	0.155
	#2		11.5	0.115
	#3		4.5	0.045

TABLE II (CONT'D)

MODEL COMPONENT: ATTACH STRUCTURE - AT_{20}

GENERAL DESCRIPTION: Aft SRB/ET attach structure (3 member structure)

MODEL SCALE: 0.010 MODEL DRAWING: SS-A00117

DRAWING NO.: VL78-000062B, VL72-000140, VL72-000115

DIMENSIONS:	MEMBER		FULL SCALE	MODEL SCALE
	#1	X_B	1317.0	13.170
		Y_B	± 57.0	± 0.570
		Z_T	457.0	4.570
		X		
		Y		
		Z		
	#2	X_B	1317.0	13.170
		Y		
		Z		
		X_T	2058.0	20.580
		Y		
		Z		
	#3	X_B	1317.0	13.170
		Y_B	± 57.0	± 0.570
		Z		
		X_T	2058.0	20.580
		Y		
		Z_T	343.0	3.430
Diameter of members, In.:	#1		6.0	0.060
	#2		6.0	0.060
	#3		6.0	0.060

TABLE II (CONT'D)

MODEL COMPONENT: ET PROTUBERANCE - PT_9

GENERAL DESCRIPTION: LOX Vent line fairing on $\overline{T}_{20}$ nose.

MODEL SCALE: 0.010 MODEL DRAWING: SS-A00117

DRAWING NO.: VL78-000062

DIMENSIONS:

		FULL SCALE	MODEL SCALE
Leading edge at:	X_T	350.9	3.509
	Y_T	0.00	0.0
Trailing edge at:	X_T	959.7	9.597
	Y_T	60.0	0.600

TABLE II (CONT'D)

MODEL COMPONENT: ET PROTUBERANCE - PT_{10}

GENERAL DESCRIPTION: LOX feedline fairing on tank T_{20} tank secured to tank.

MODEL SCALE: 0.010

DRAWING NO.: VL78-000062

DIMENSIONS:

		FULL SCALE	MODEL SCALE
Leading edge at:	X_T	985.7	9.857
	Y_T	- 70.0	- 0.700
Trailing edge at:	X_T	2071.50	20.715
	Y_T	- 70.0	- 0.70

TABLE II (CONT'D)

MODEL COMPONENT: ET PROTUBERANCE - PT_{11}

GENERAL DESCRIPTION: LH_2 feedline fairing on T_{20} tank secured to tank.

MODEL SCALE: 0.010

DRAWING NO.: VL78-000031A

DIMENSIONS:

		FULL SCALE	MODEL SCALE
Leading edge at:	X_T	985.70	9.875
	Y_T	70.00	0.70
Trailing edge at:	X_T	2071.50	20.715
	Y_T	70.00	0.70

Centerline of LH_2 feedline radially located at $\emptyset = -34.5^\circ$

TABLE II. (CONT'D)

MODEL COMPONENT: ET PROTUBERANCE - PT_{12}

GENERAL DESCRIPTION: Lightning rod attached to ET nose.

MODEL SCALE: 0.010

DRAWING NO. VL78-000068A

DIMENSIONS:	FULL SCALE	MODEL SCALE
Length	30.90	0.309
Diameter, In.	3.20	0.032

TABLE II (CONT'D)

MODEL COMPONENT: FEEDLINE - FL_3

GENERAL DESCRIPTION: LOX feedline between ET and orbiter.

MODEL SCALE: 0.010 MODEL DRAWING: SS-A00117

DRAWING NO.: VL78-000062, VL72-000131

DIMENSIONS:

		FULL SCALE	MODEL SCALE
Centerline at:	X_T	2017.50	20.175
	Y_T	70.00	0.700
	X_o	1330.50	13.305
	Y_o	70.00	0.700
	Diameter	18.80	0.188

TABLE II (CONT'D)

MODEL COMPONENT: FEEDLINE - FL_4

GENERAL DESCRIPTION: LH_2 feedline between ET and orbiter.

MODEL SCALE: 0.010 MODEL DRAWING NO.: SS-A00117

DRAWING NO.: VL78-000062, VL72-000131

DIMENSIONS:

		FULL SCALE	MODEL SCALE
Centerline at:	X_T	2017.50	20.175
	Y_T	- 70.00	- 0.70
	X_o	1330.50	13.305
	Y_o	- 70.00	- 0.700
Diameter		18.80	0.188

Notes:

1. Positive directions of force coefficients, moment coefficients, and angles are indicated by arrows
2. For clarity, origins of wind and stability axes have been displaced from the center of gravity

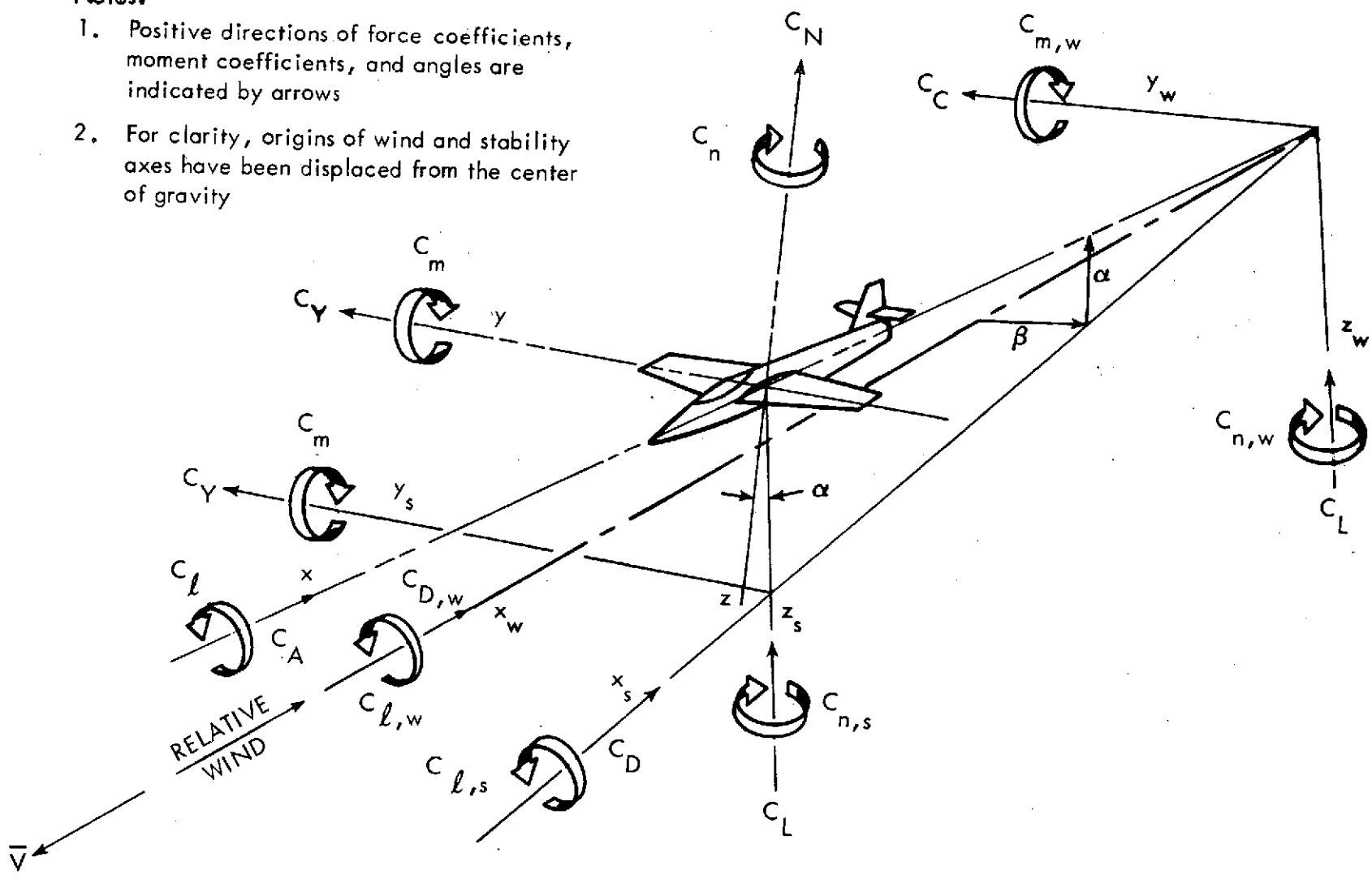
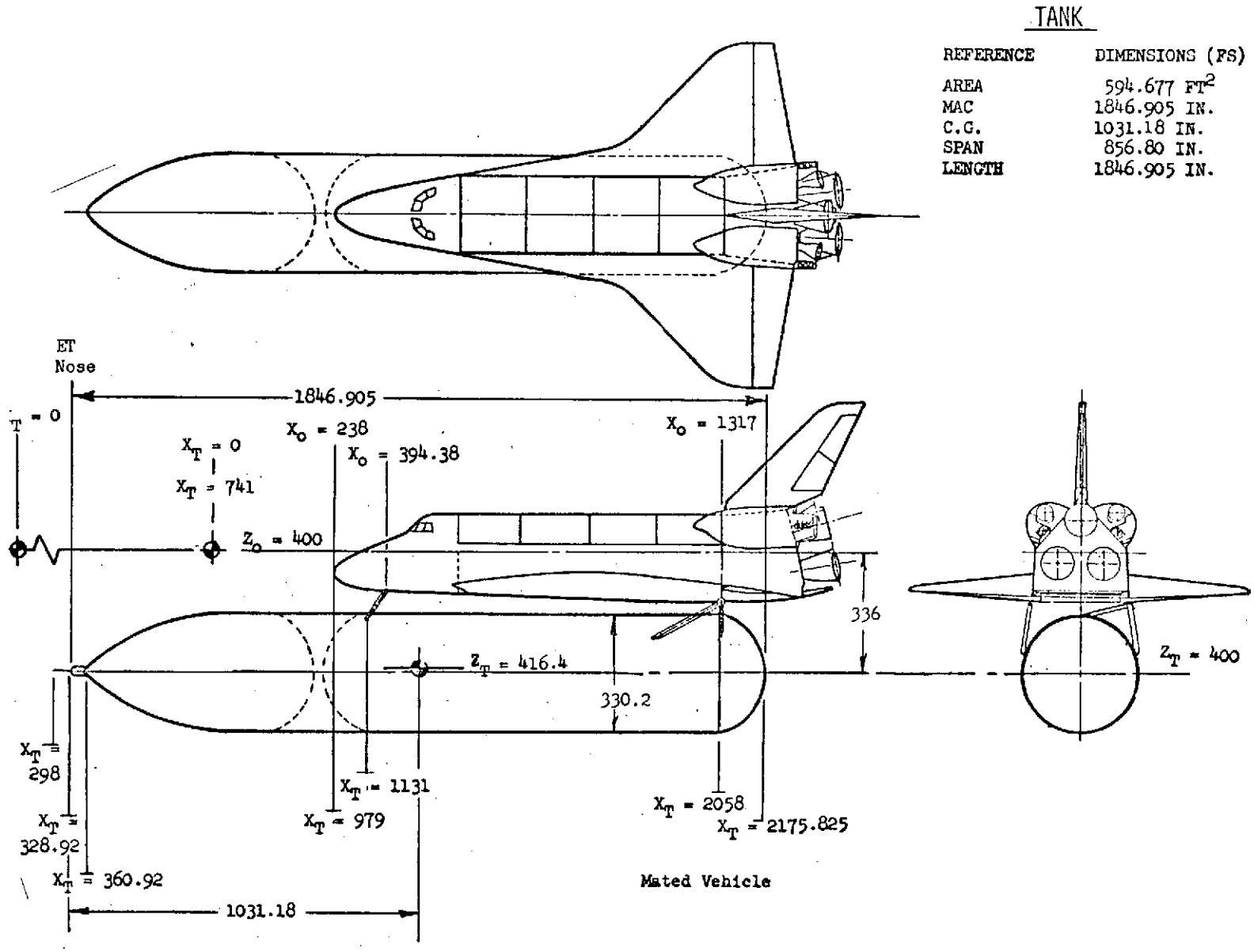
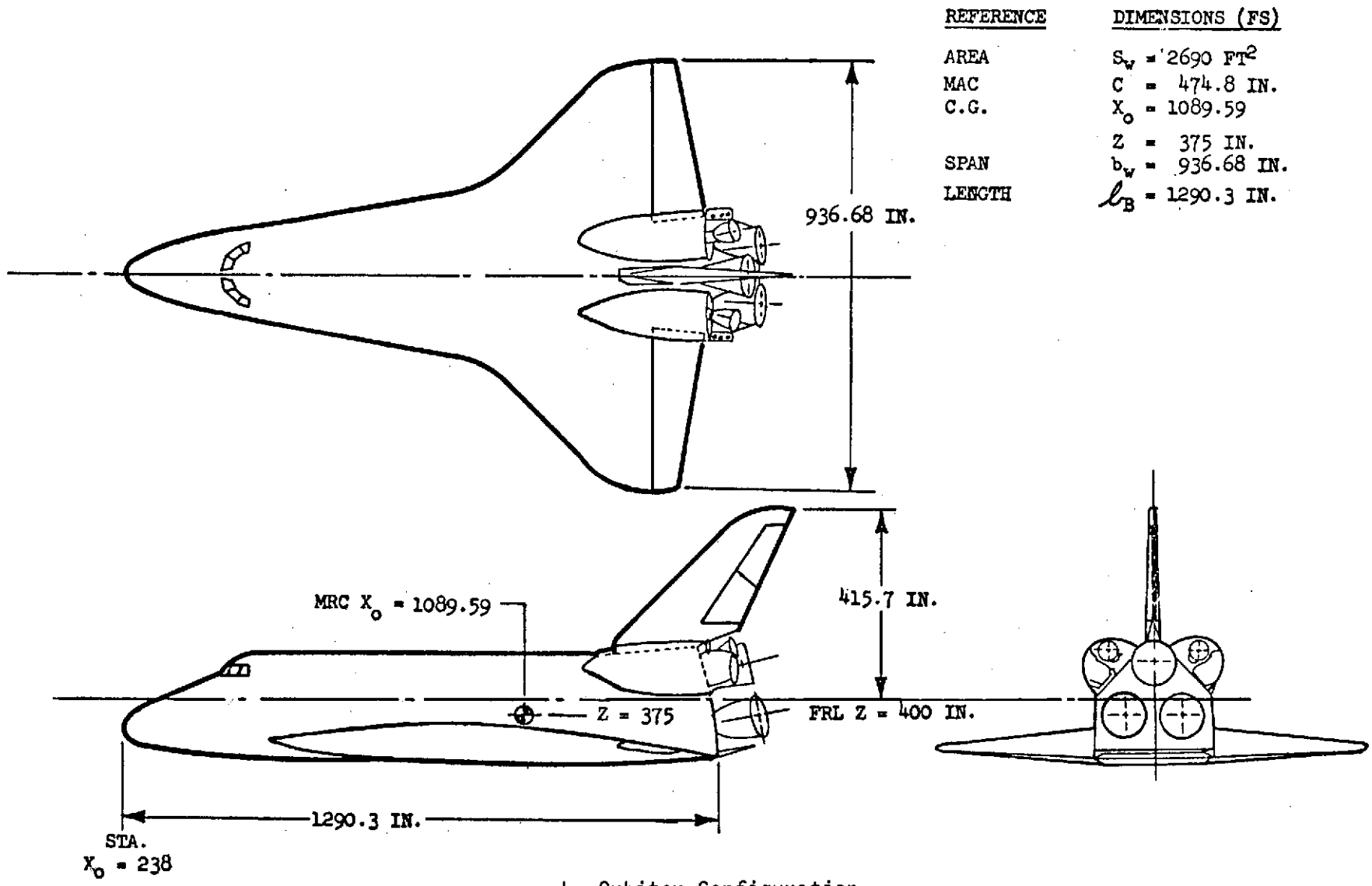


Figure 1. - Axis systems.



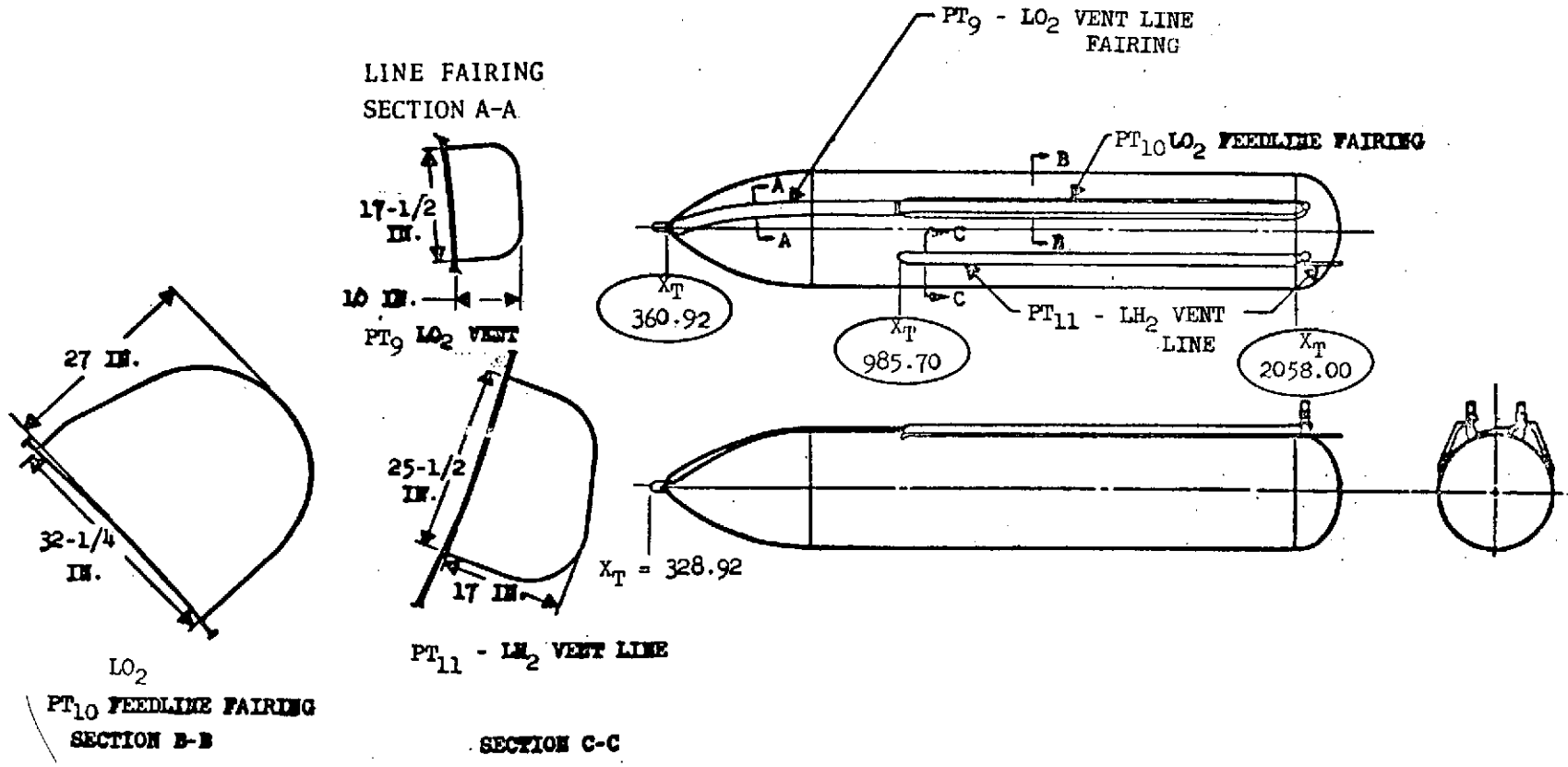
a. Orbiter/Tank Mated Configuration

Figure 2. - Model sketches.



b. Orbiter Configuration

Figure 2. - Continued.



c. External Tank Protuberances

Figure 2. - Concluded.

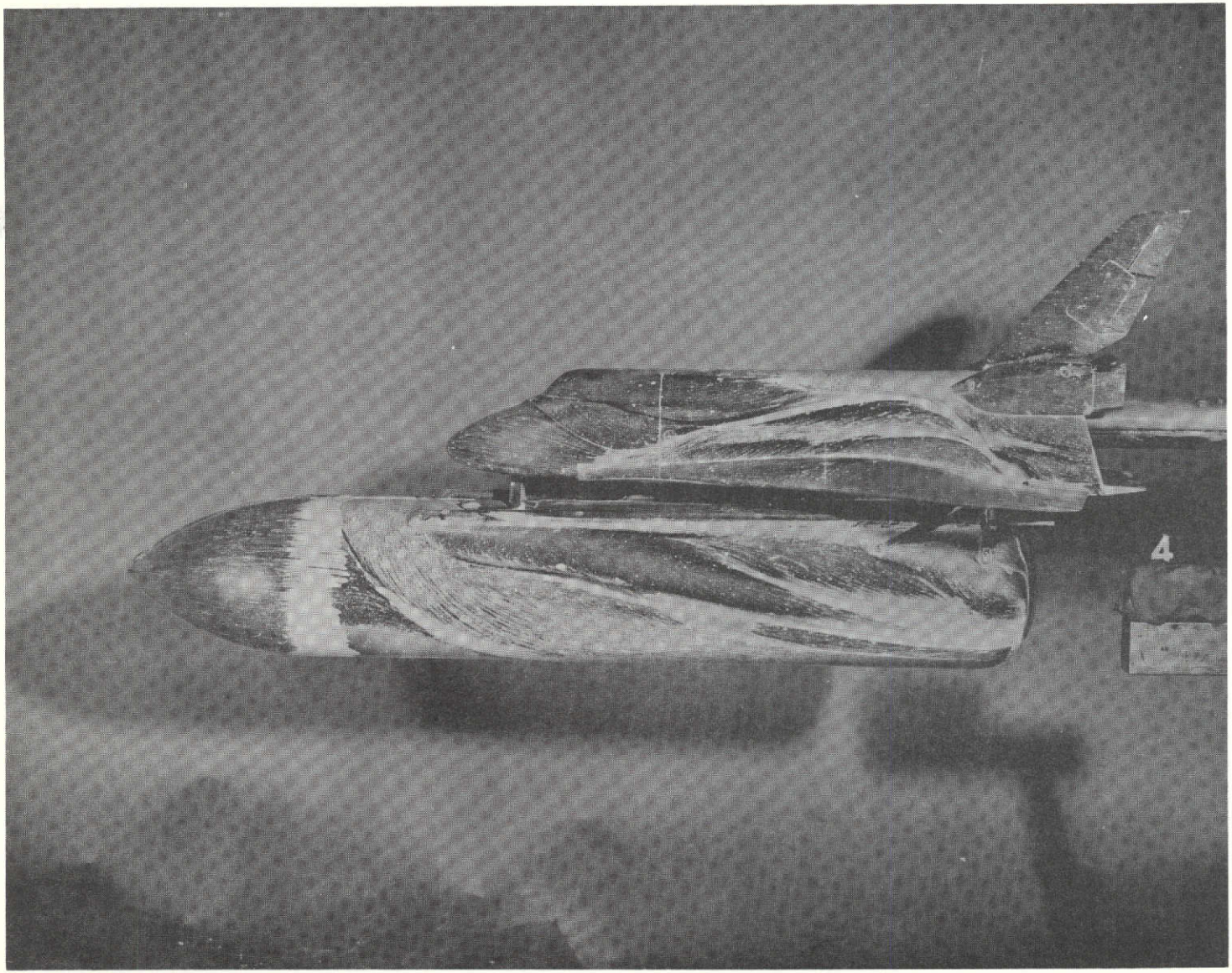


Figure 3. Run Number 4, View Left side

$\alpha = 0°$, $\beta = 0°$ Configuration Mated

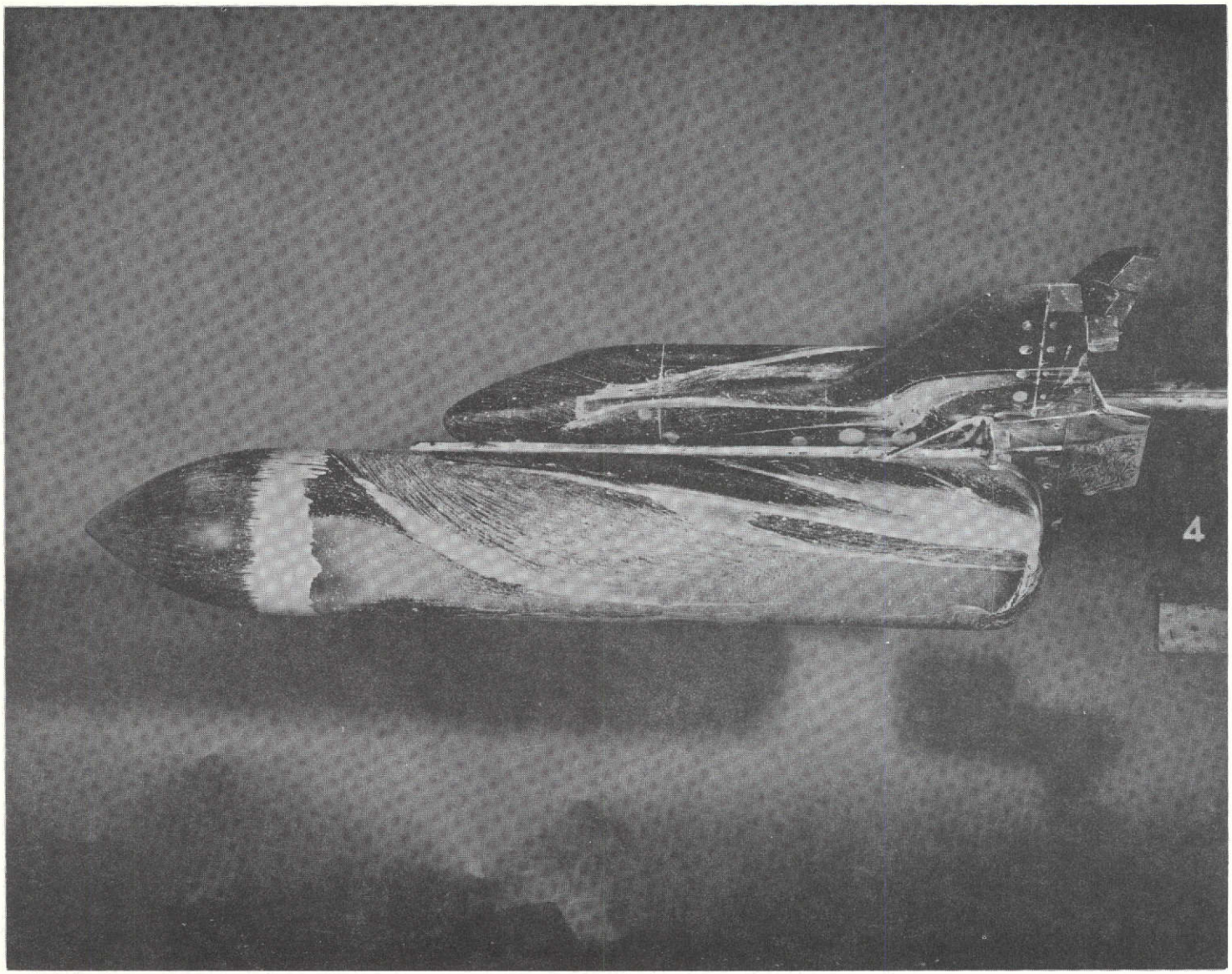


Figure 4. Run Number 4, View Lower left side

$\alpha = 0°, \beta = 0°$ Configuration Mated

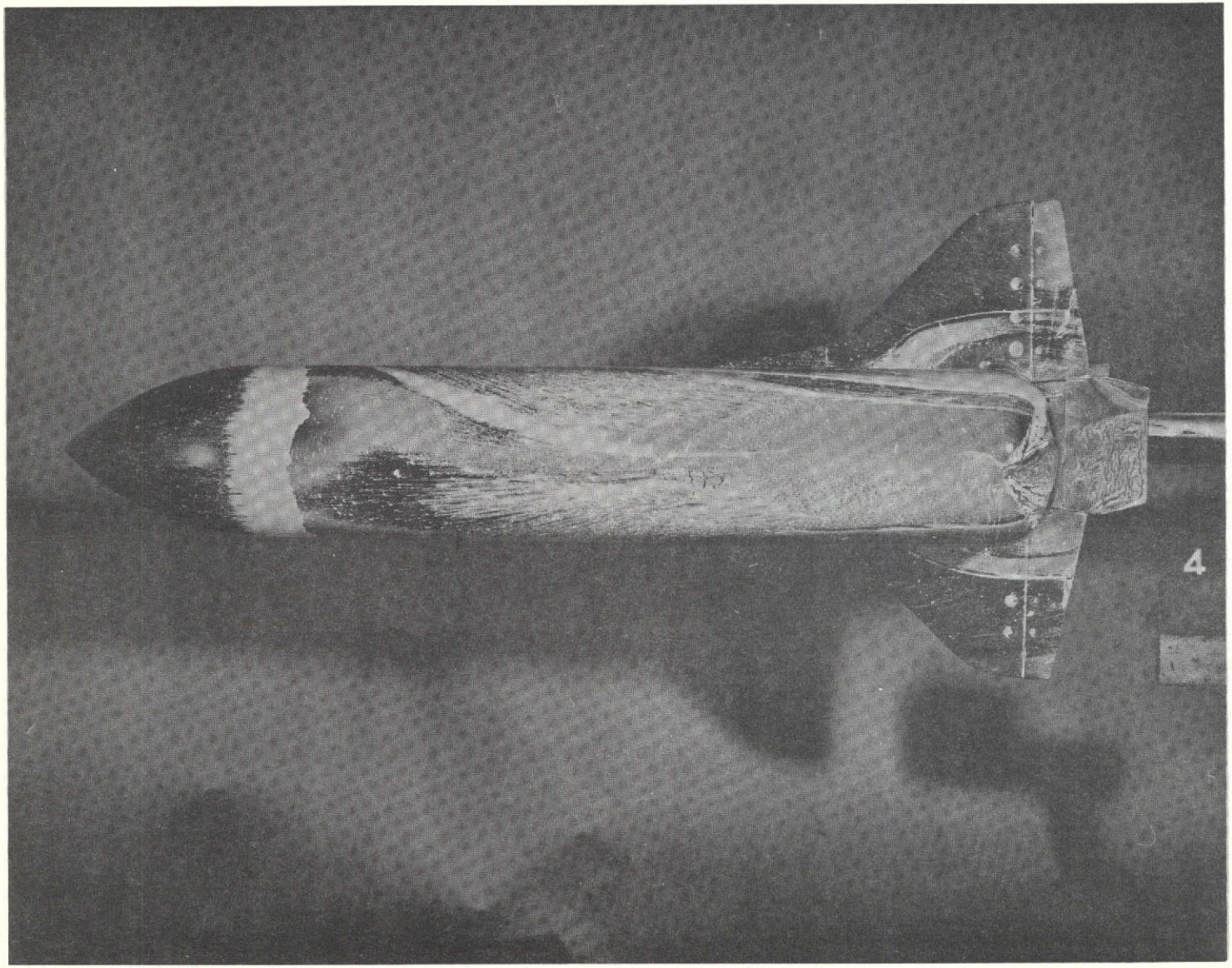


Figure 5. Run Number 4, View Bottom

$\alpha = 0°$, $\beta = 0°$ Configuration Mated

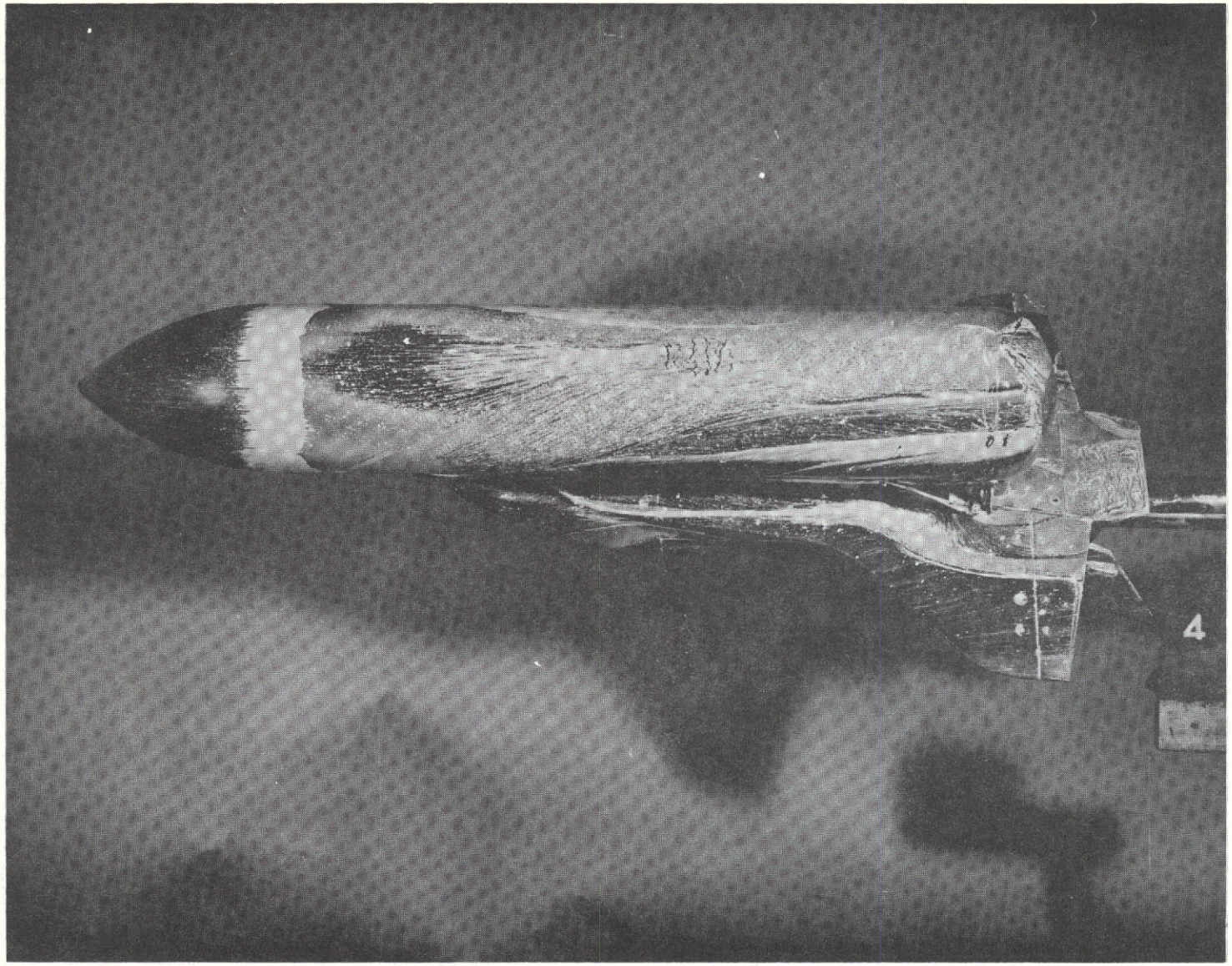


Figure 6. Run Number 4 View Lower right side

$\alpha = 0°$, $\beta = 0°$ Configuration Mated

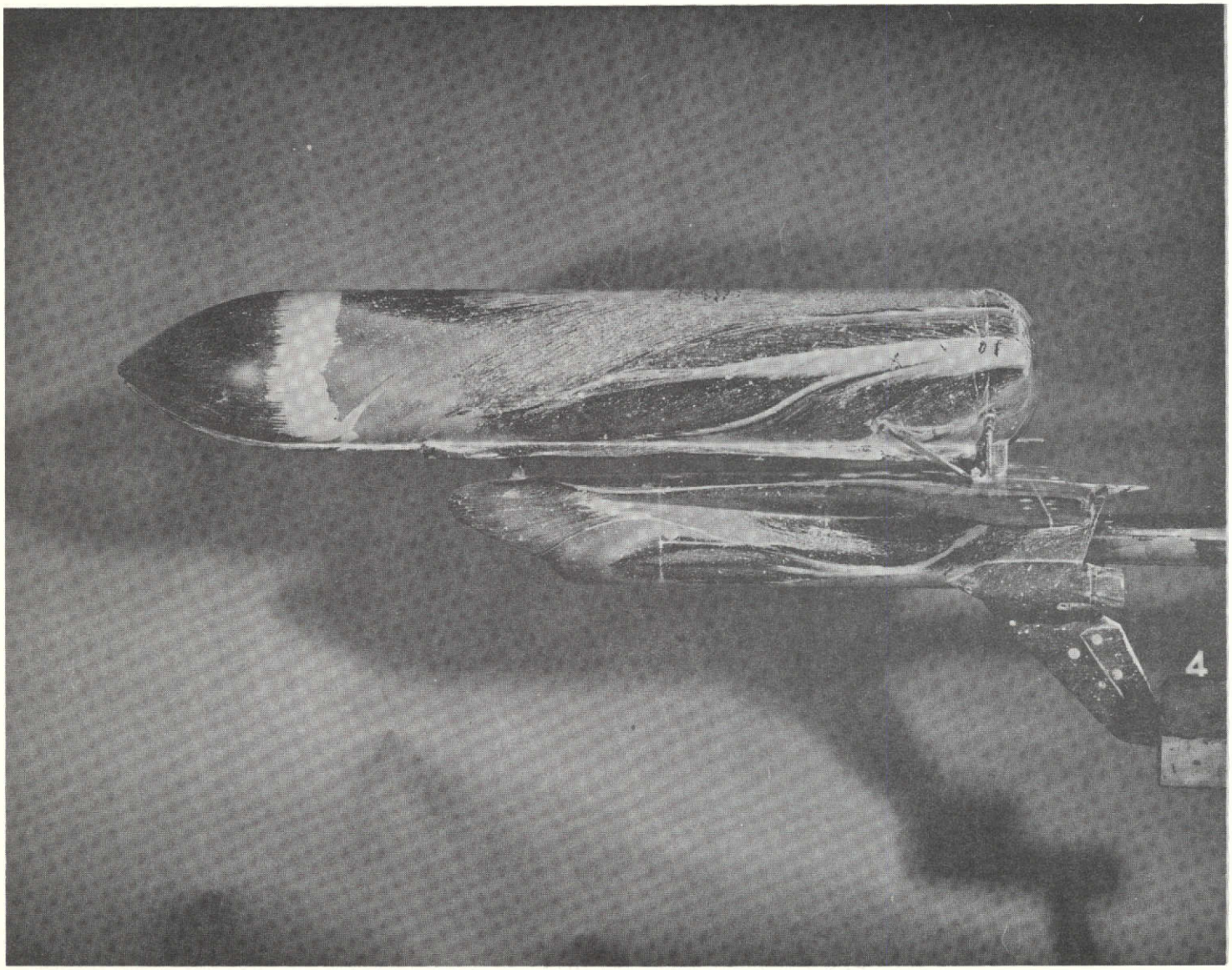


Figure 7. Run Number 4 View Right side

$\alpha = 0°$, $\beta = 0°$ Configuration Mated

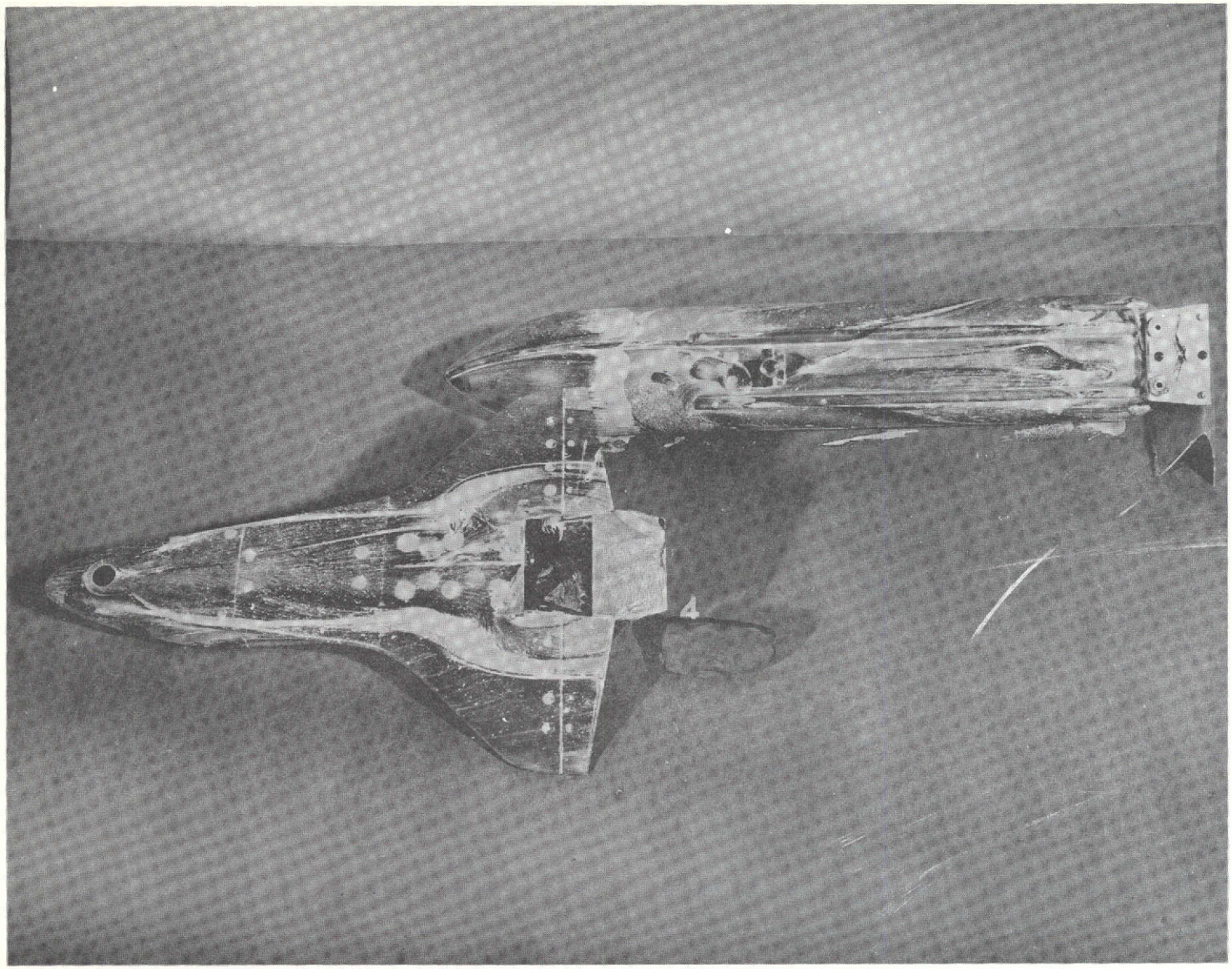


Figure 8. Run Number 4 View Interference regions

$\alpha = 0°$, $\beta = 0°$ Configuration Mated

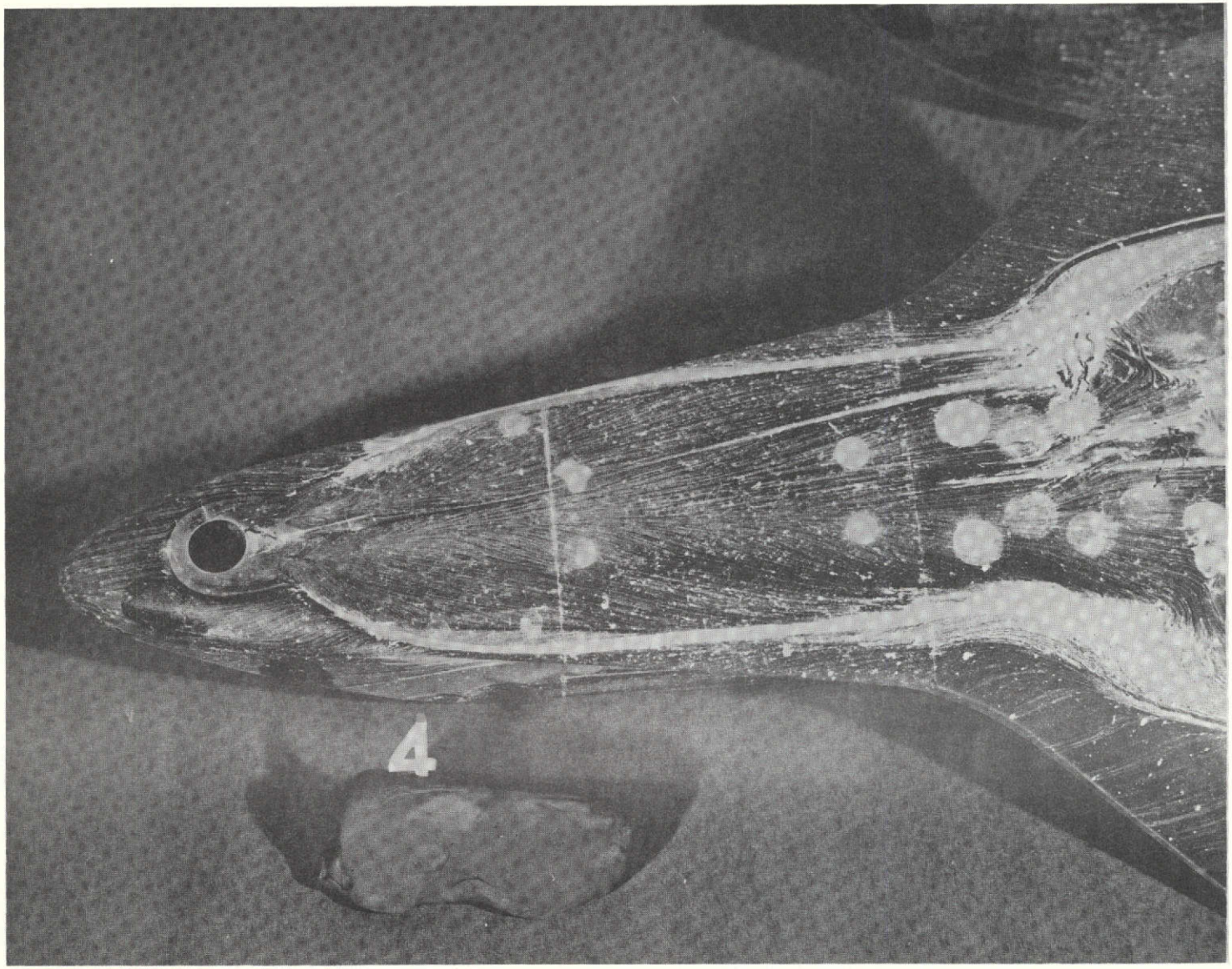


Figure 9. Run Number 4 View Orbiter forward bottom

$\alpha = 0°$, $\beta = 0°$ Configuration Mated

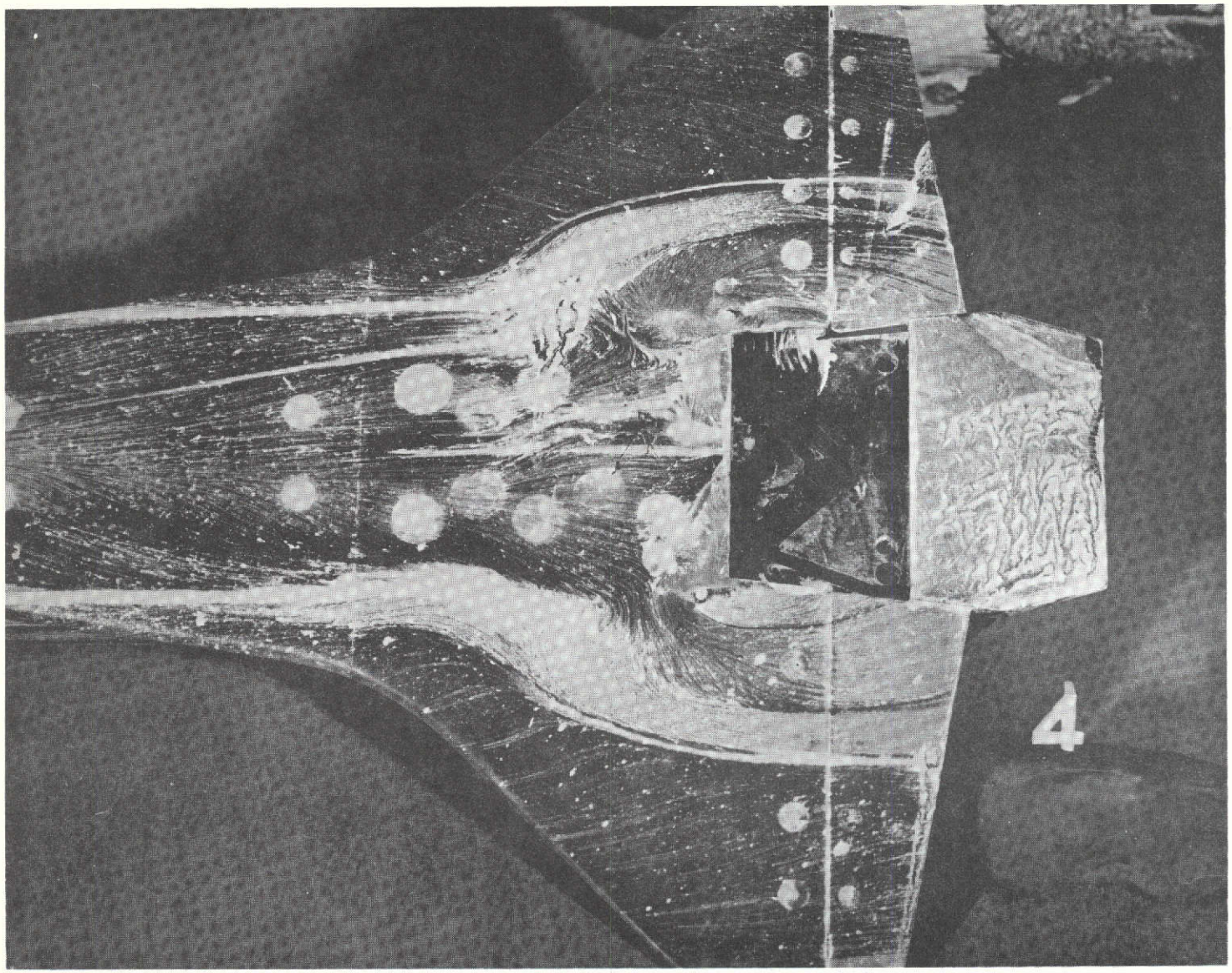


Figure 10. Run Number 4 View Orbiter rear bottom

$\alpha = 0°$, $\beta = 0°$ Configuration Mated

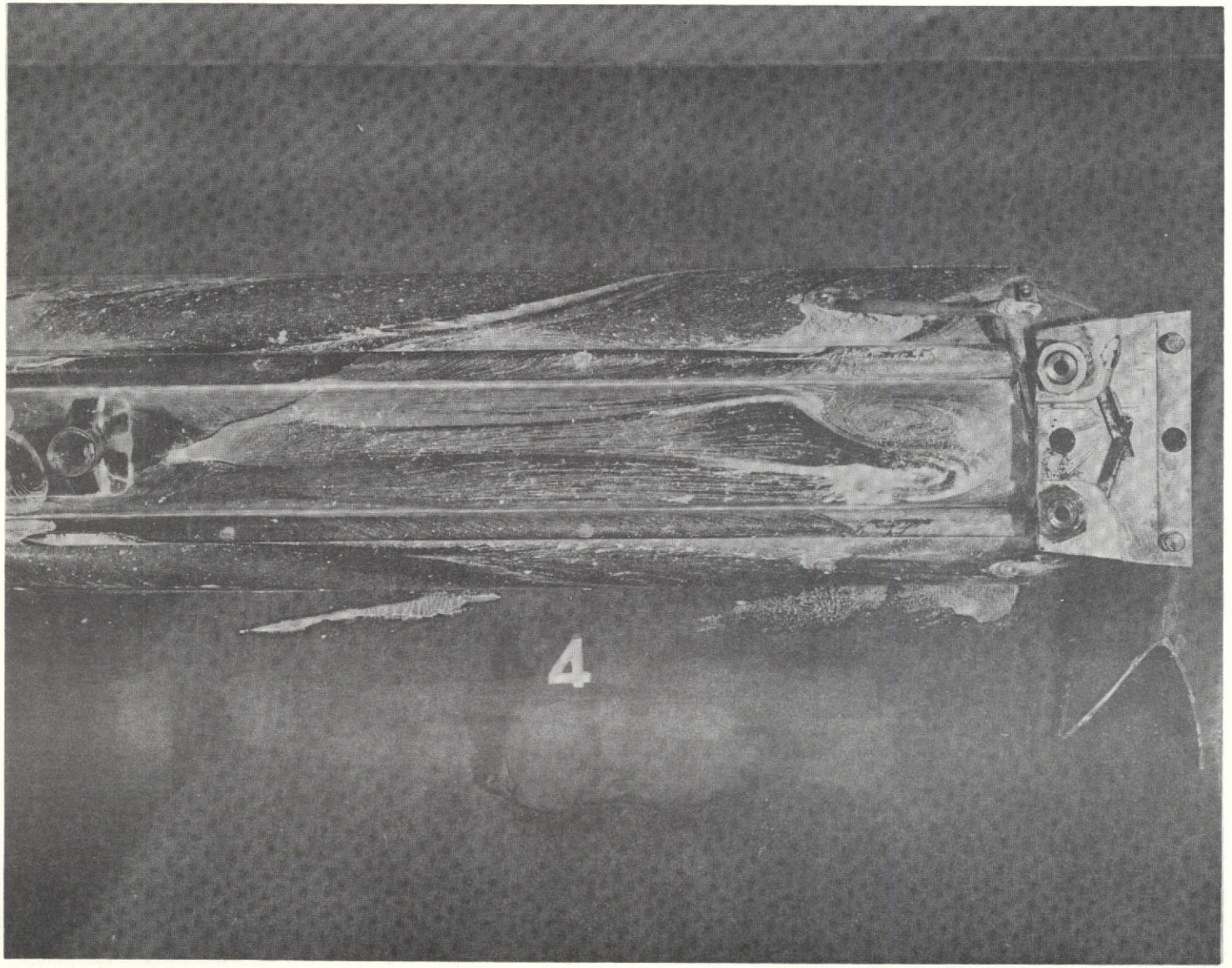


Figure 11. Run Number 4 View Tank top

$\alpha = 0°$, $\beta = 0°$ Configuration Mated

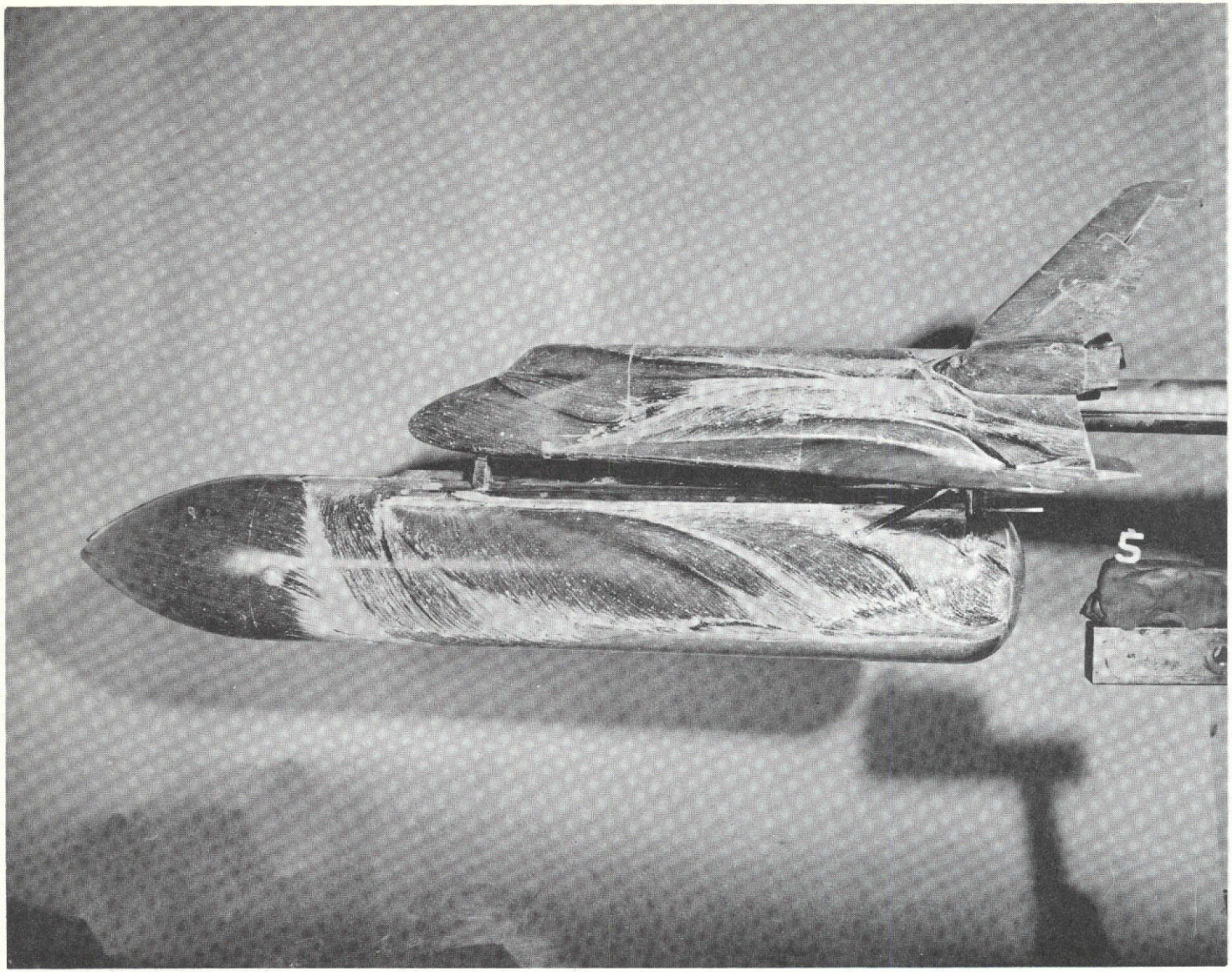


Figure 12. Run Number 5 View Left side

$\alpha = -5°, \beta = 0°$ Configuration Mated

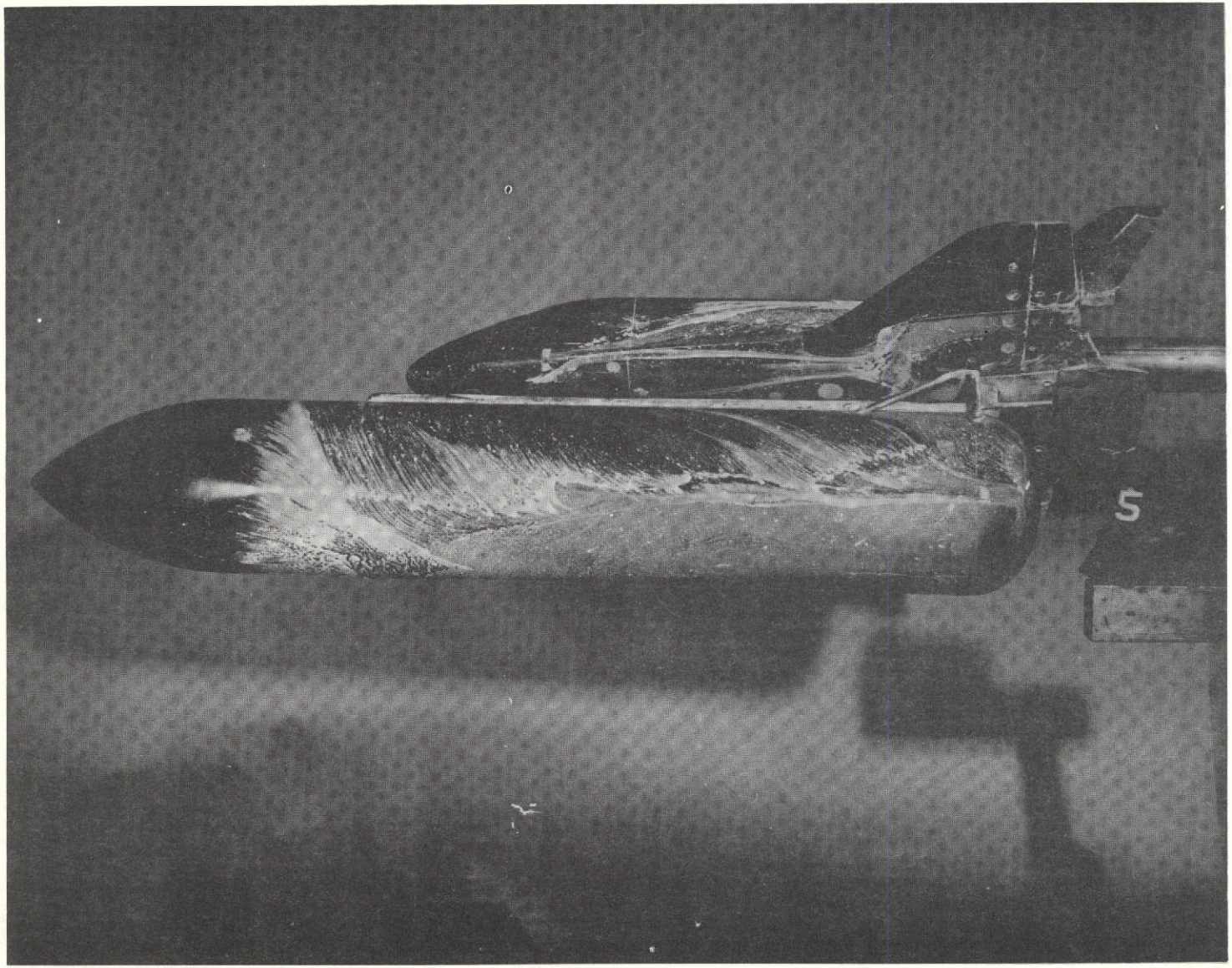


Figure 13. Run Number 5 View Lower Left side
$\alpha = 5°$, $\beta = 0°$ Configuration Mated

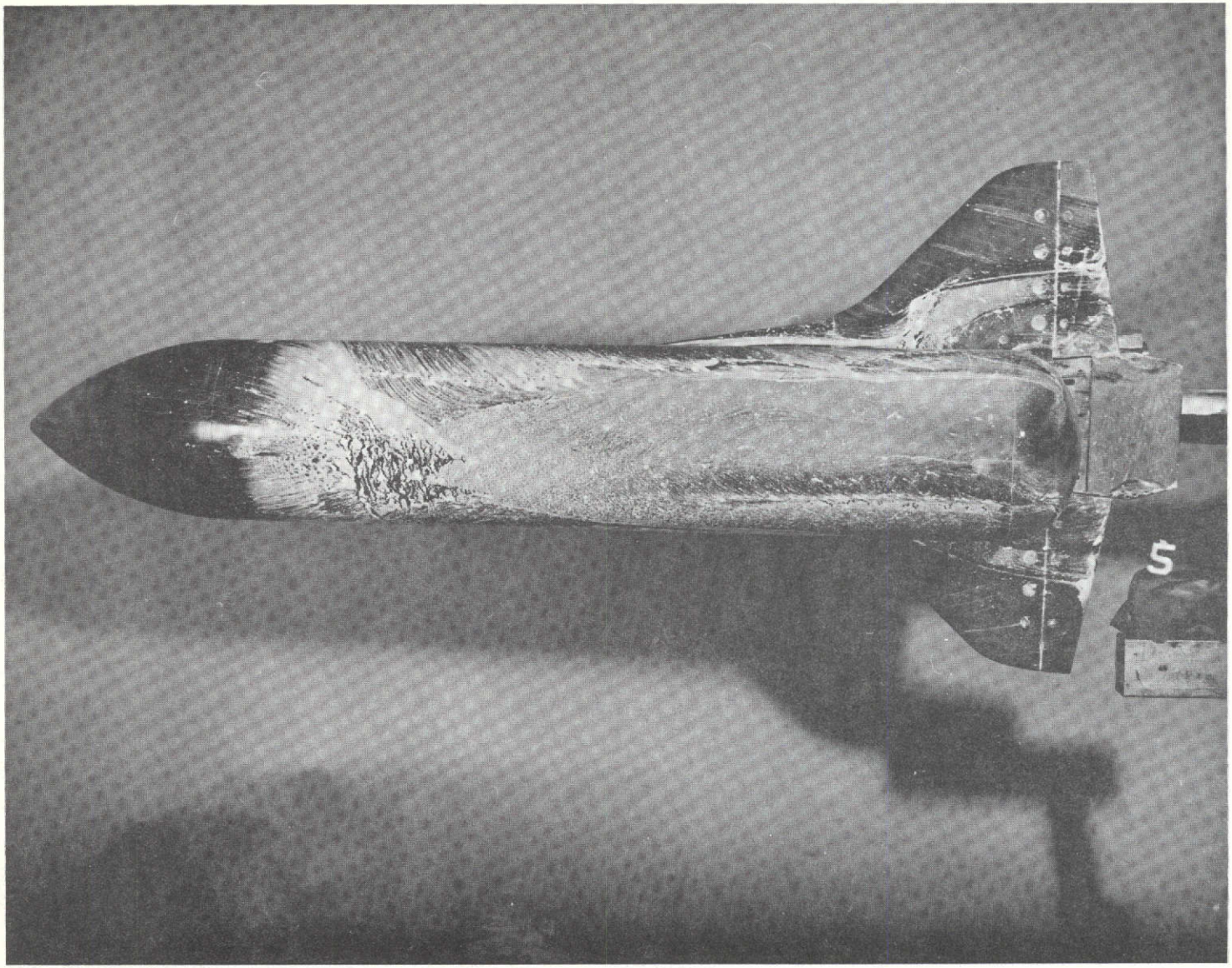


Figure 14. Run Number 5 View Bottom

$\alpha = -5°$, $\beta = 0°$ Configuration Mated

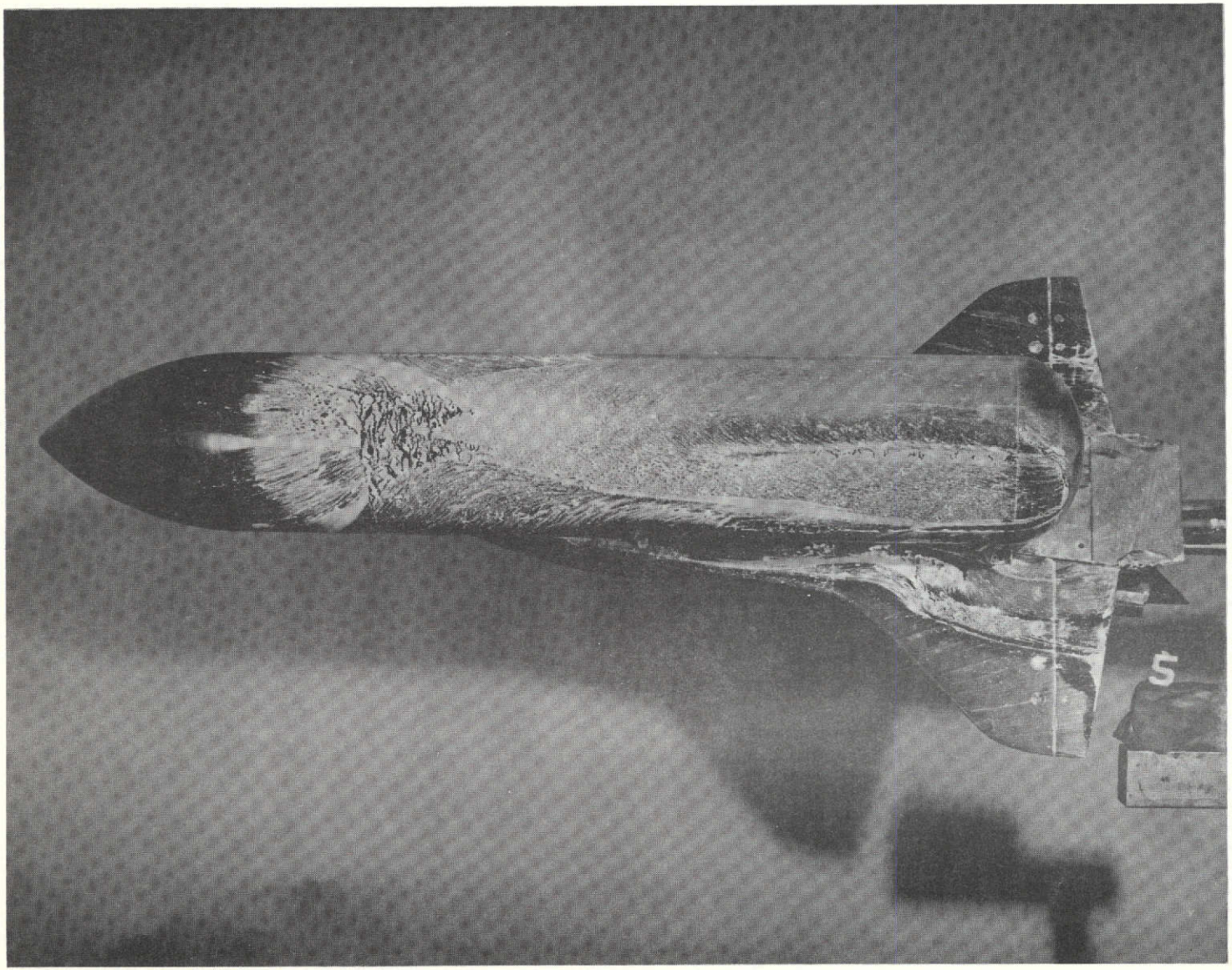


Figure 15. Run Number 5 View Lower right side

α = -5°, β = 0° Configuration Mated

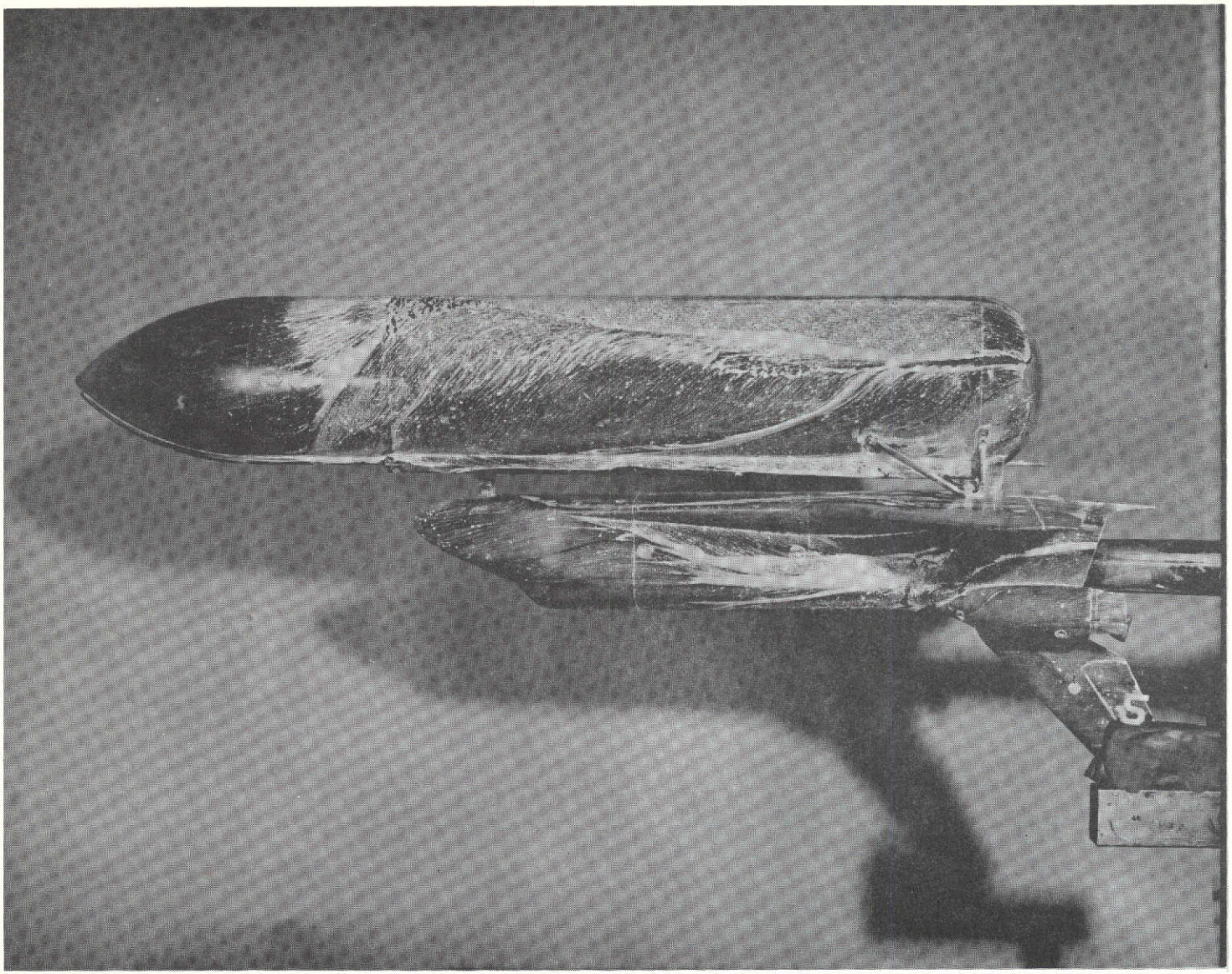


Figure 16. Run Number 5 View Right Side α = -5°, β = 0° Configuration Mated

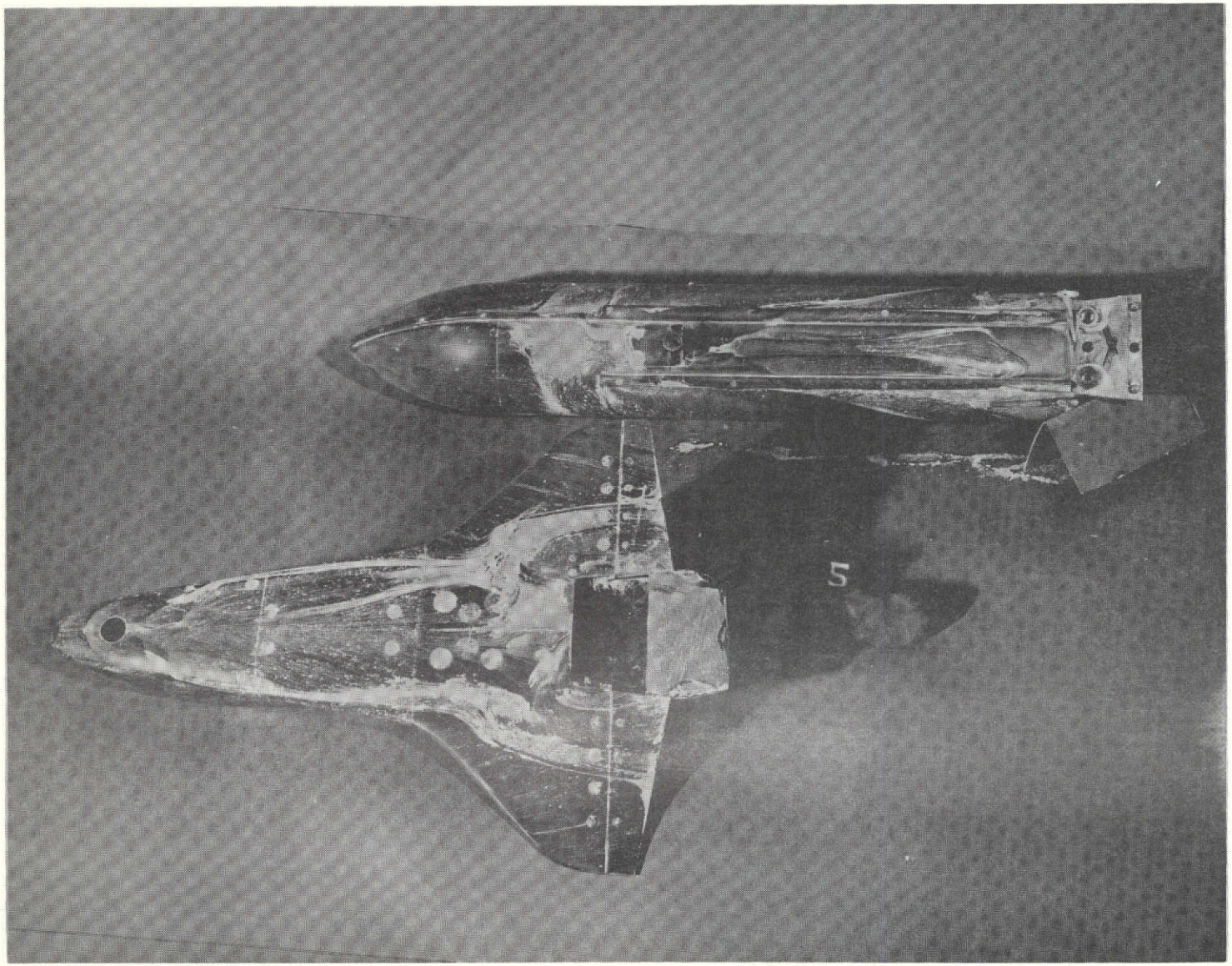


Figure 17. Run Number 5 View Interference regions

α = -5°, β = 0° Configuration Mated

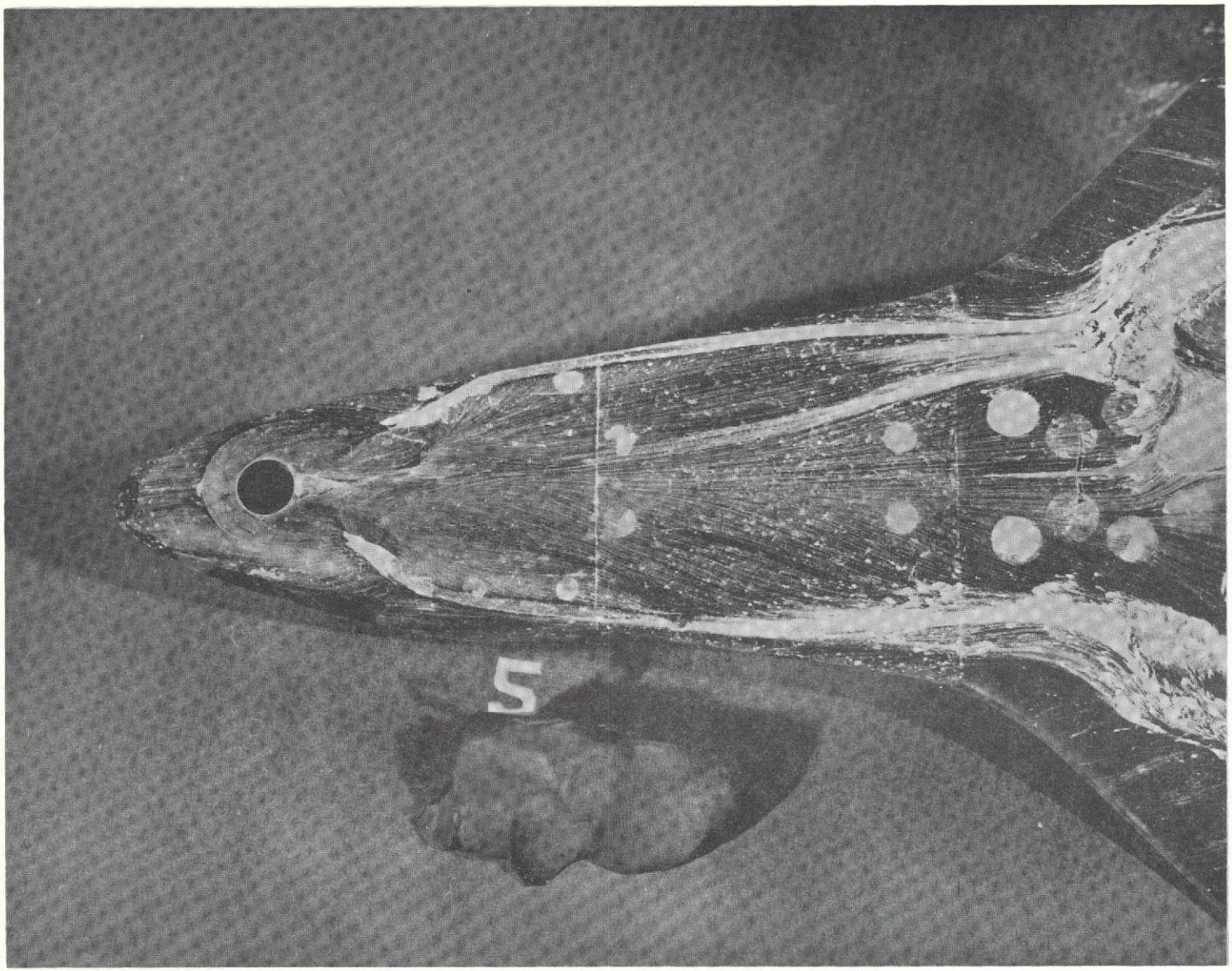


Figure 18. Run Number 5 View Orbiter Forward Bottom
$\alpha = 5°$, $\beta = 0°$ Configuration Mated

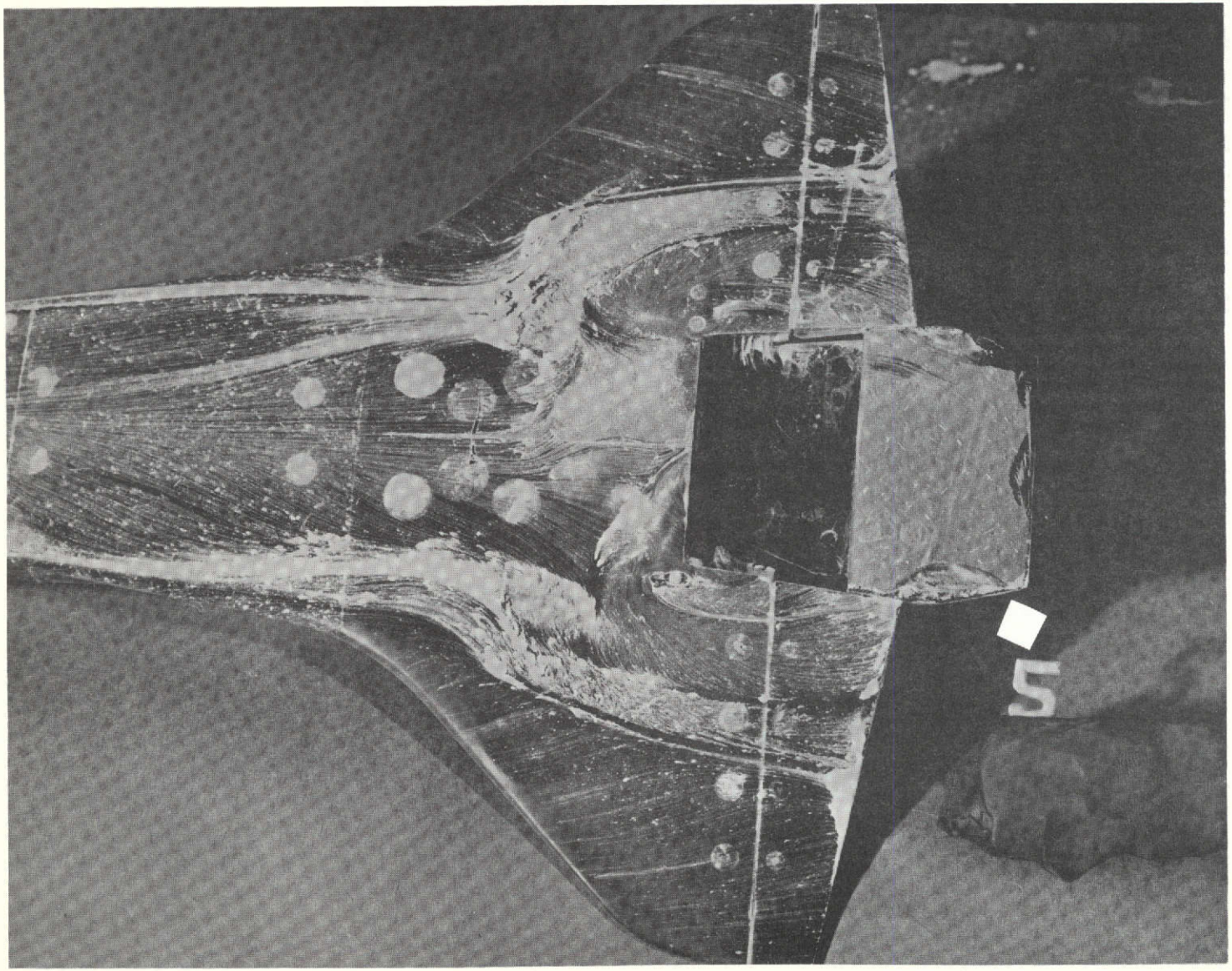


Figure 19. Run Number 5 View Orbiter rear bottom

α = -5°, β = 0° Configuration Mated

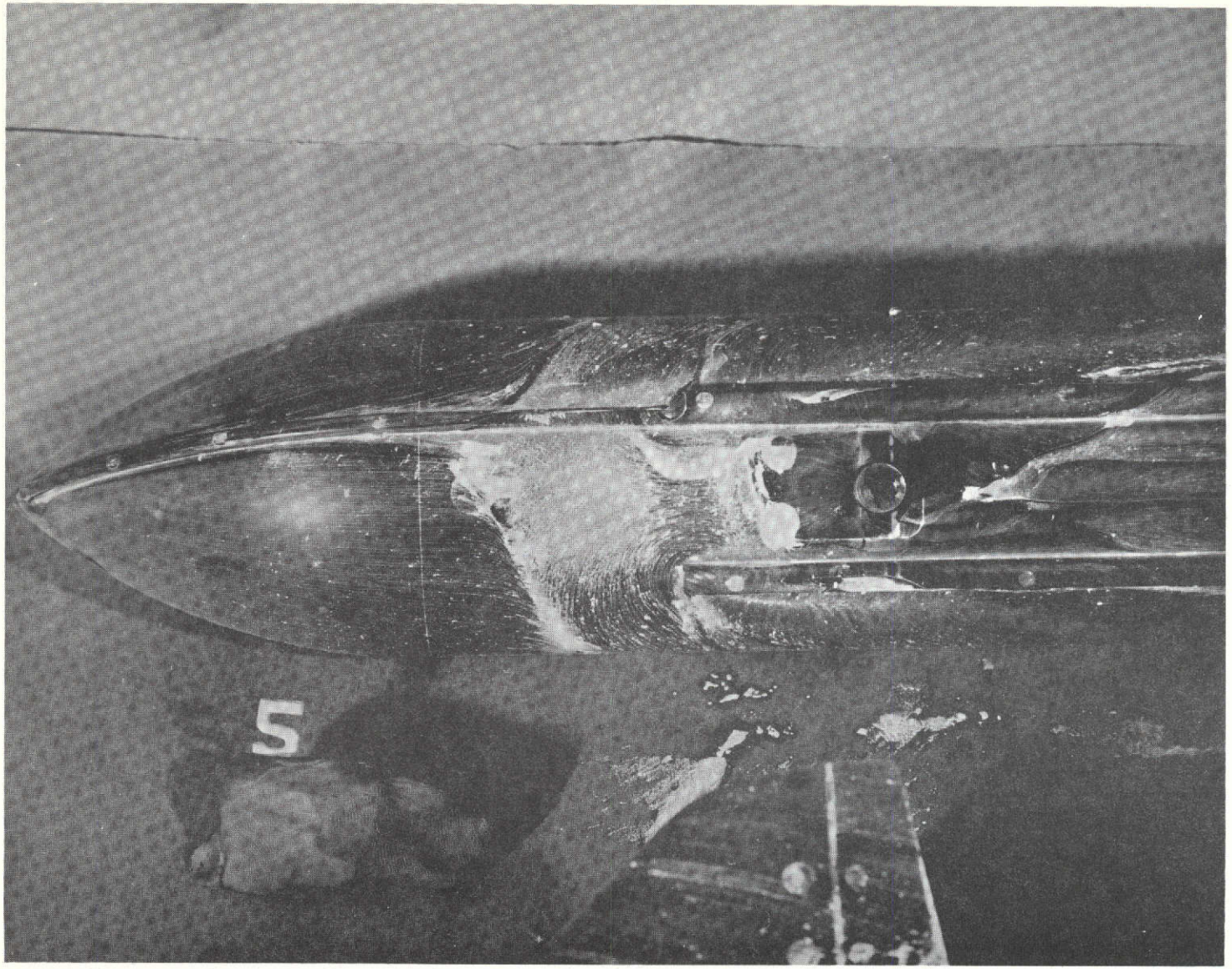


Figure 20. Run Number 5 View Tank forward top

α = -5°, β = 0° Configuration Mated

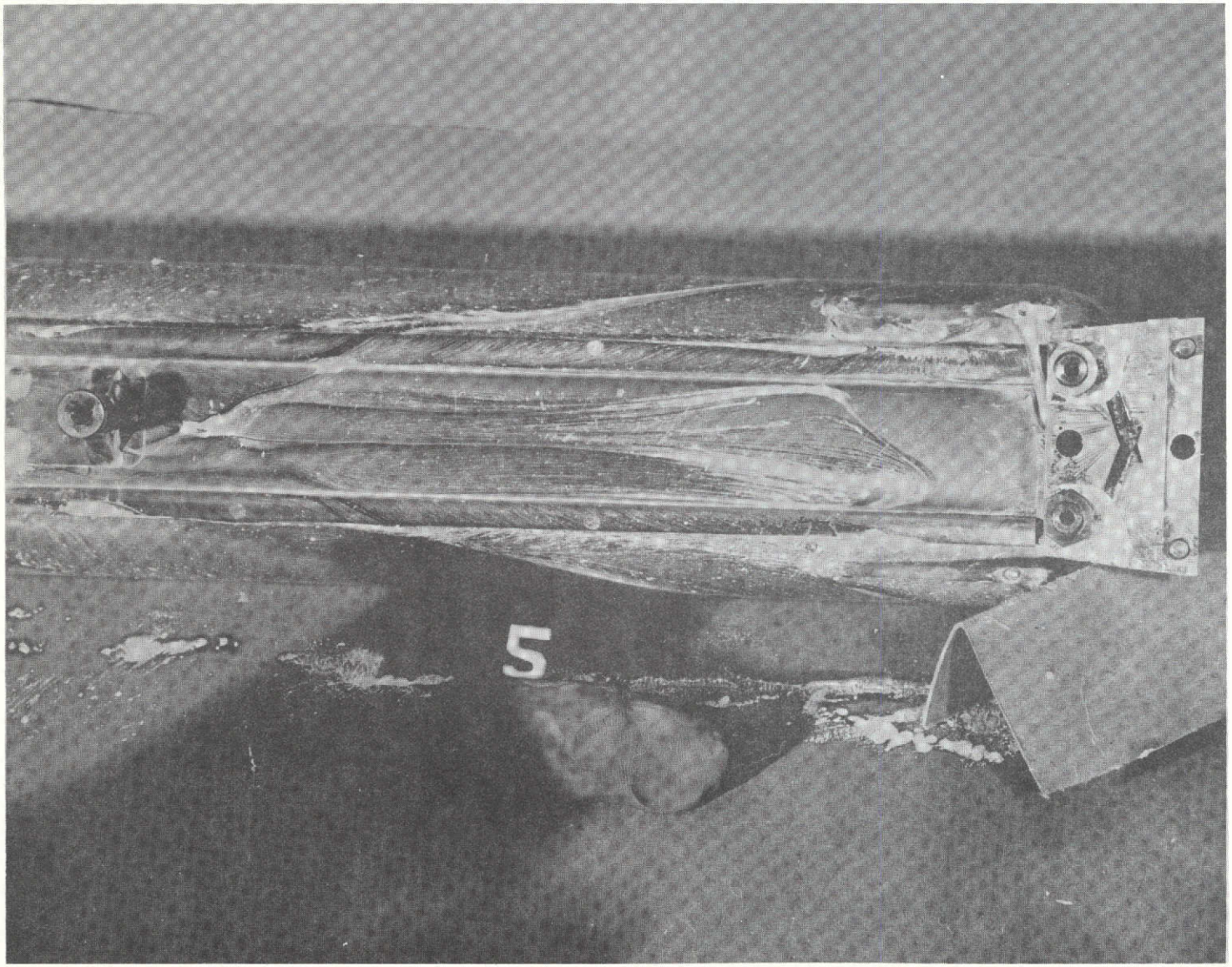


Figure 21. Run Number 5 View Tank rear top

α = -5°, β = 0° Configuration Mated

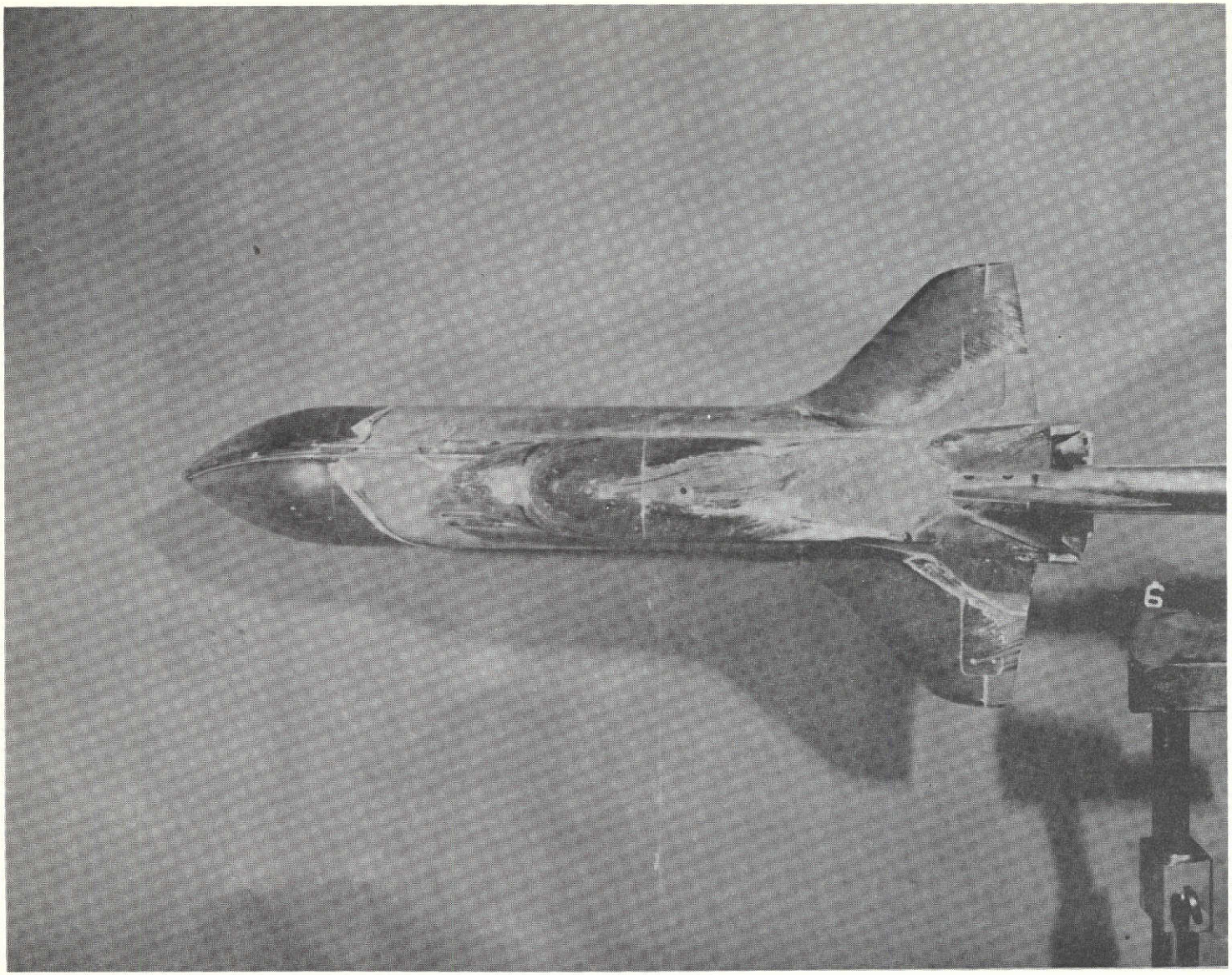


Figure 22. Run Number 6 View Top

$\alpha = 0°$, $\beta = 2°$ Configuration Mated

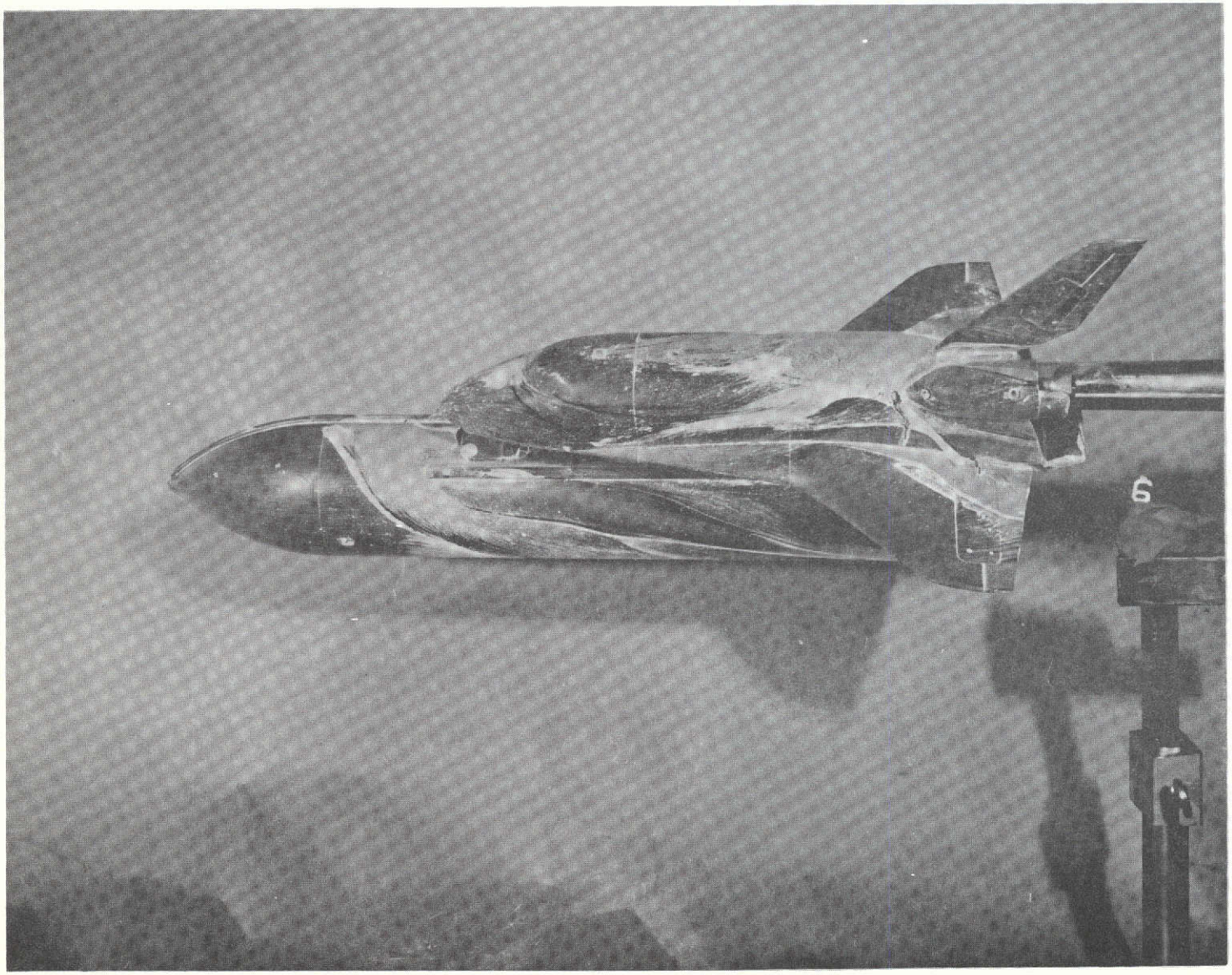


Figure 23. Run Number 6 View Upper left side

$\alpha = 0°$, $\beta = 2°$ Configuration Mated

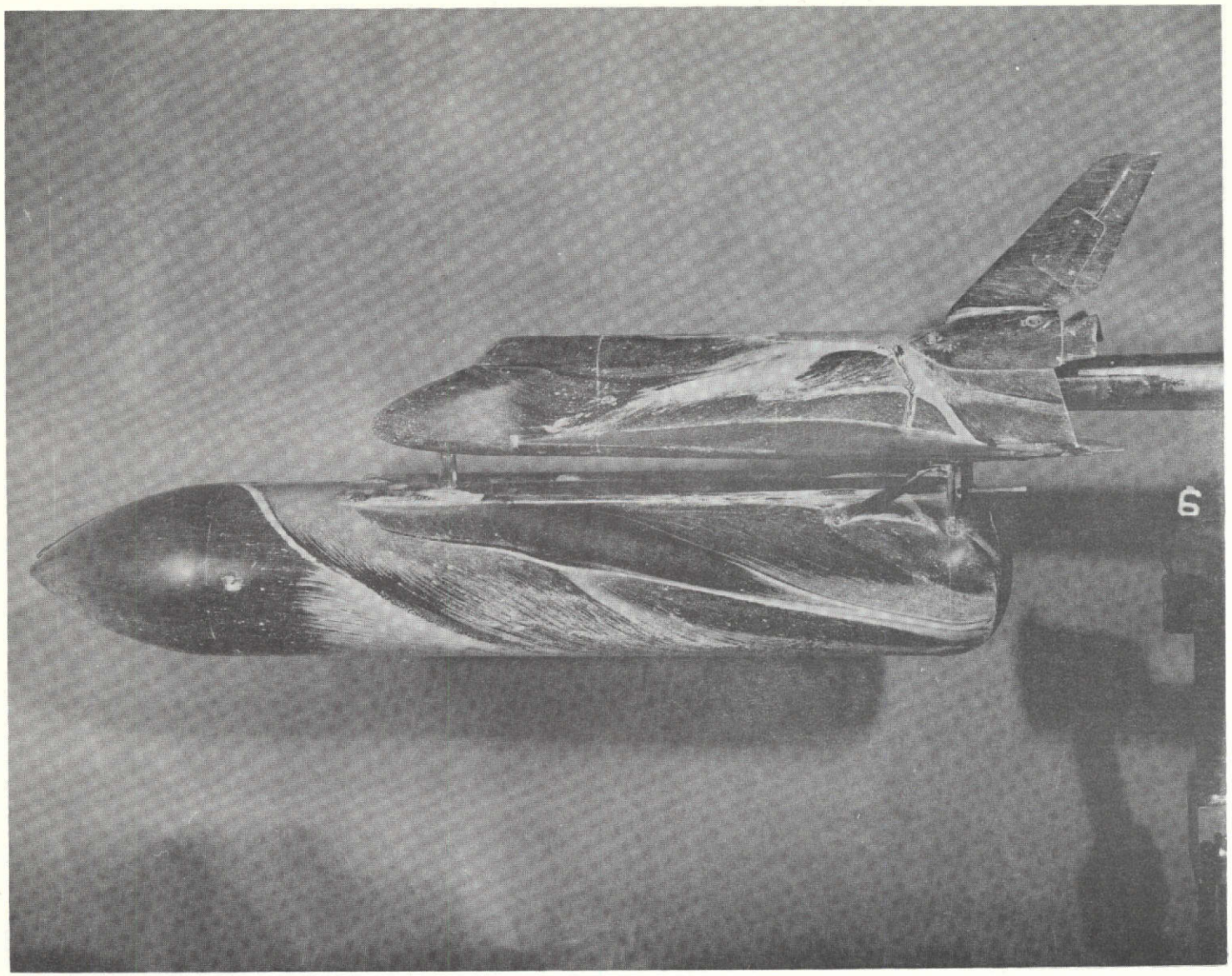


Figure 24. Run Number 6 View Left side

$\alpha = 0°$, $\beta = 2°$ Configuration Mated

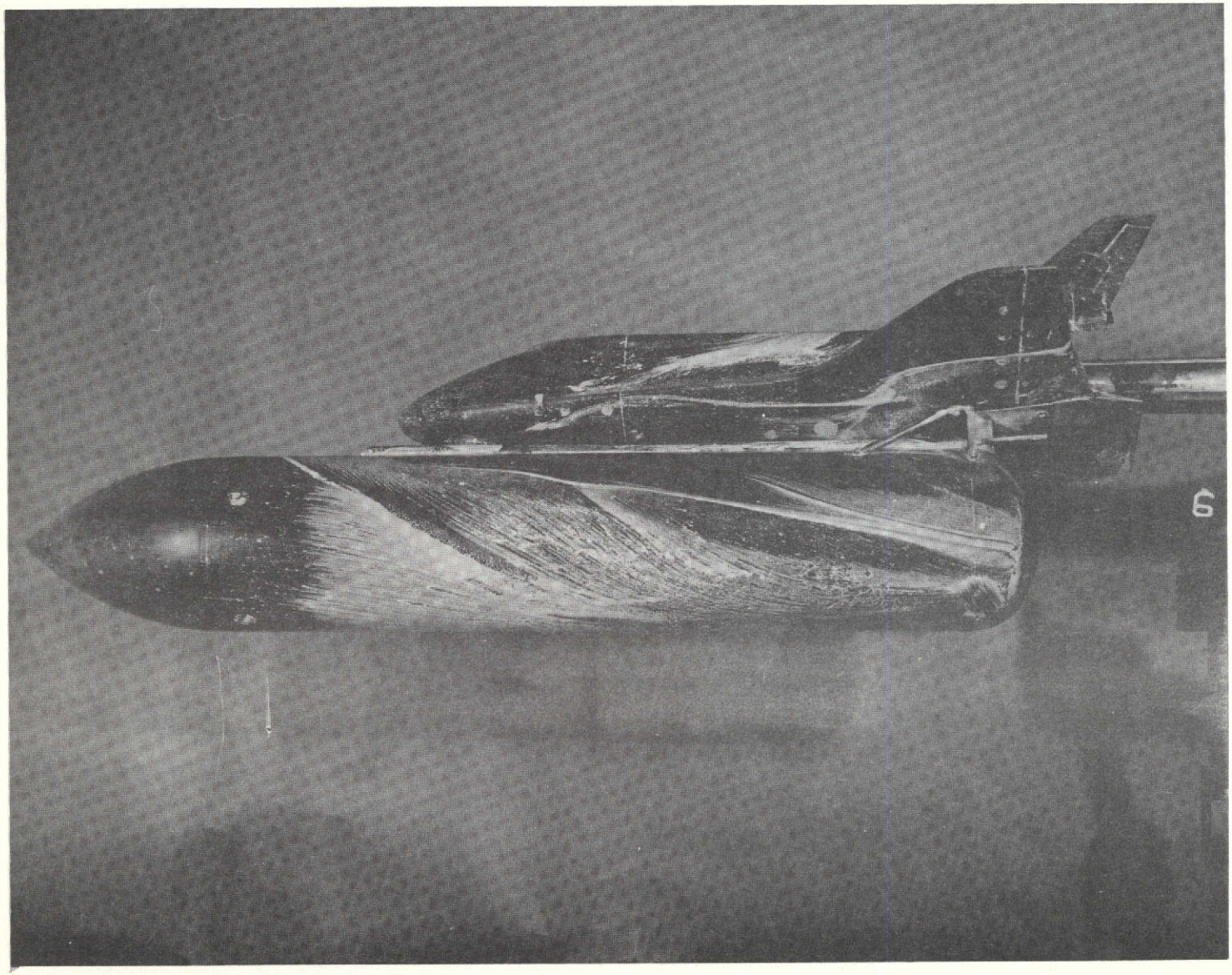


Figure 25. Run Number 6 View Lower left side

$\alpha = 0°$, $\beta = 2°$ Configuration Mated

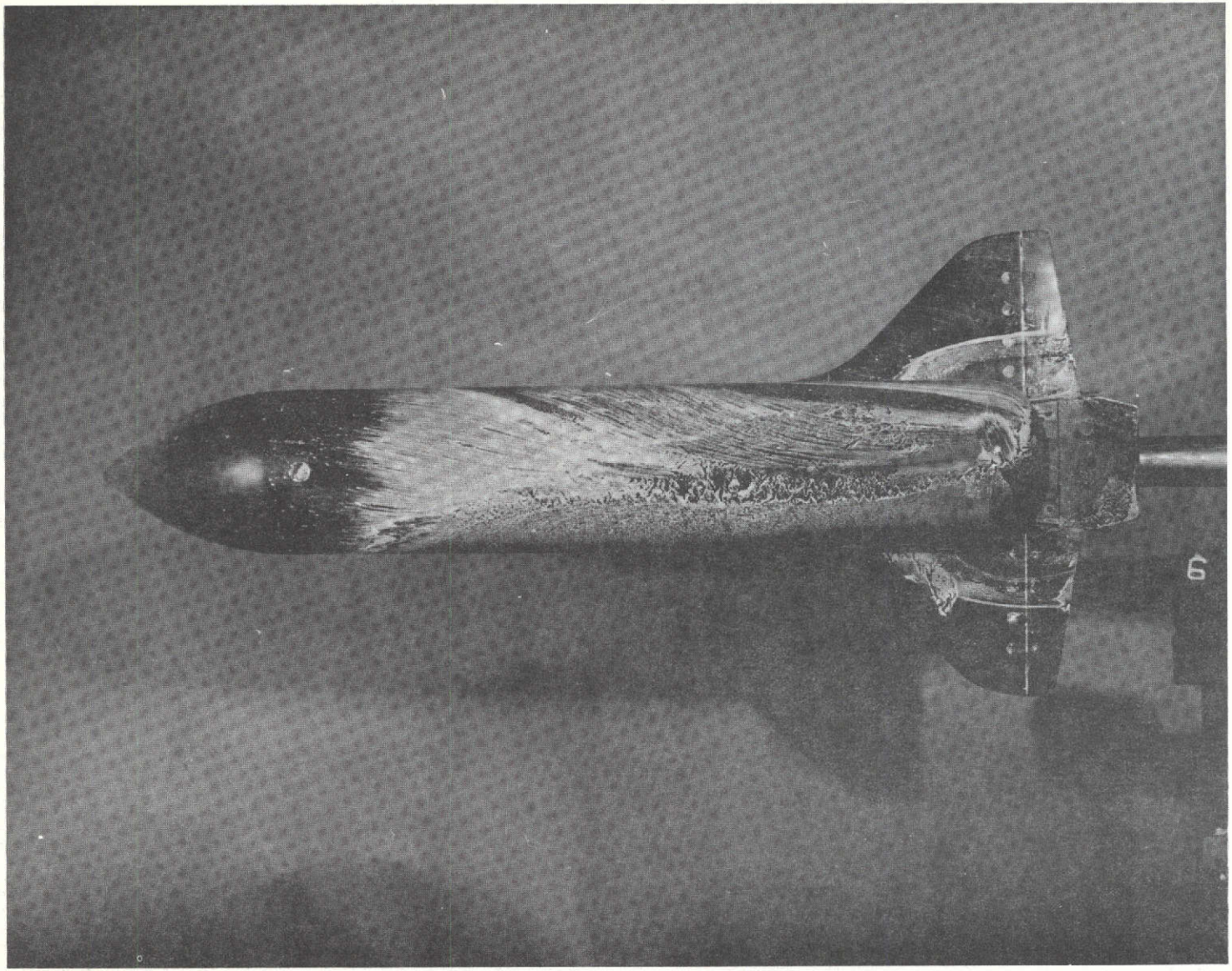


Figure 26. Run Number 6 View Bottom

$\alpha = 0°$, $\beta = 2°$ Configuration Mated

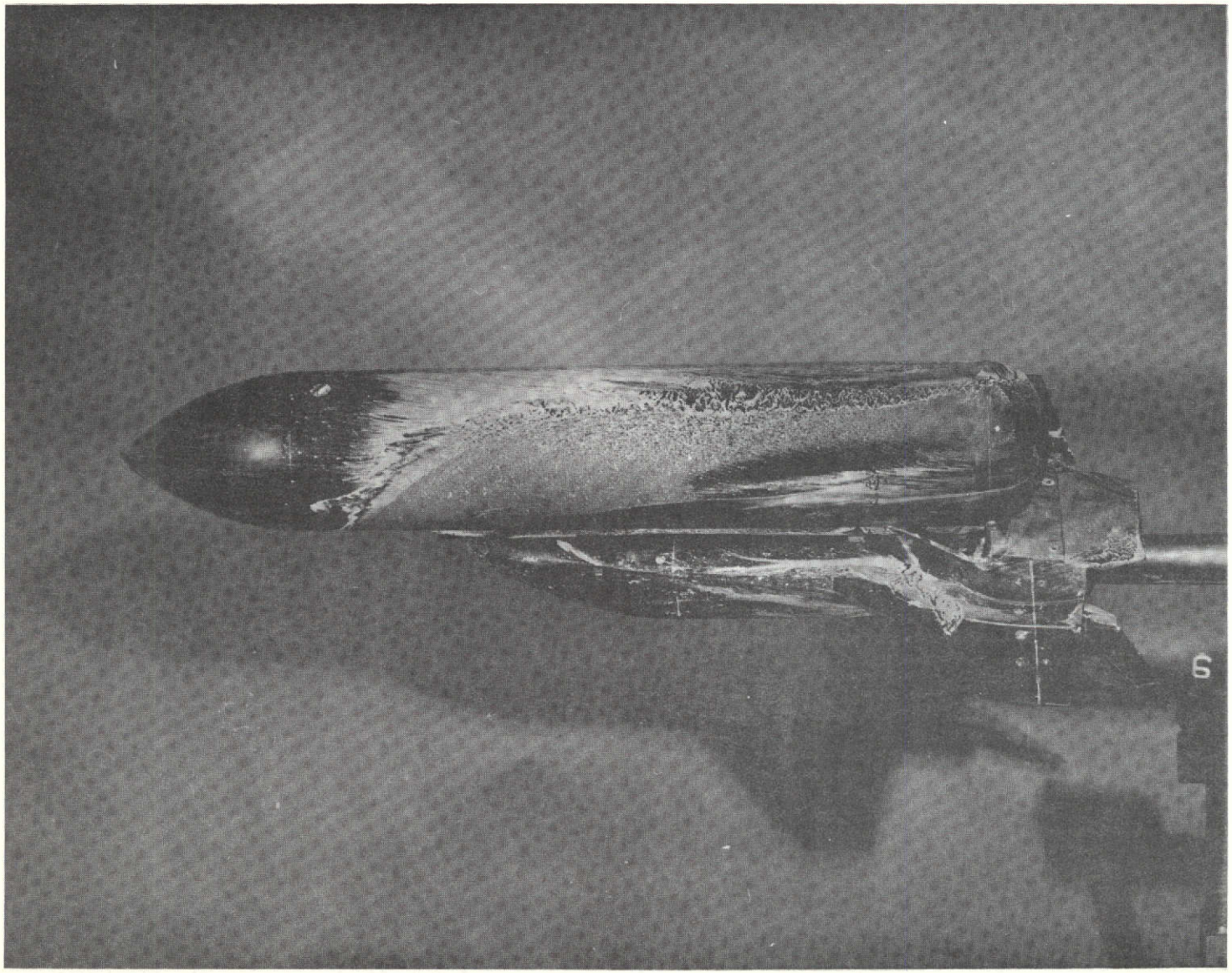


Figure 27. Run Number 6 View Lower right side

$\alpha = 0°$, $\beta = 2°$ Configuration Mated

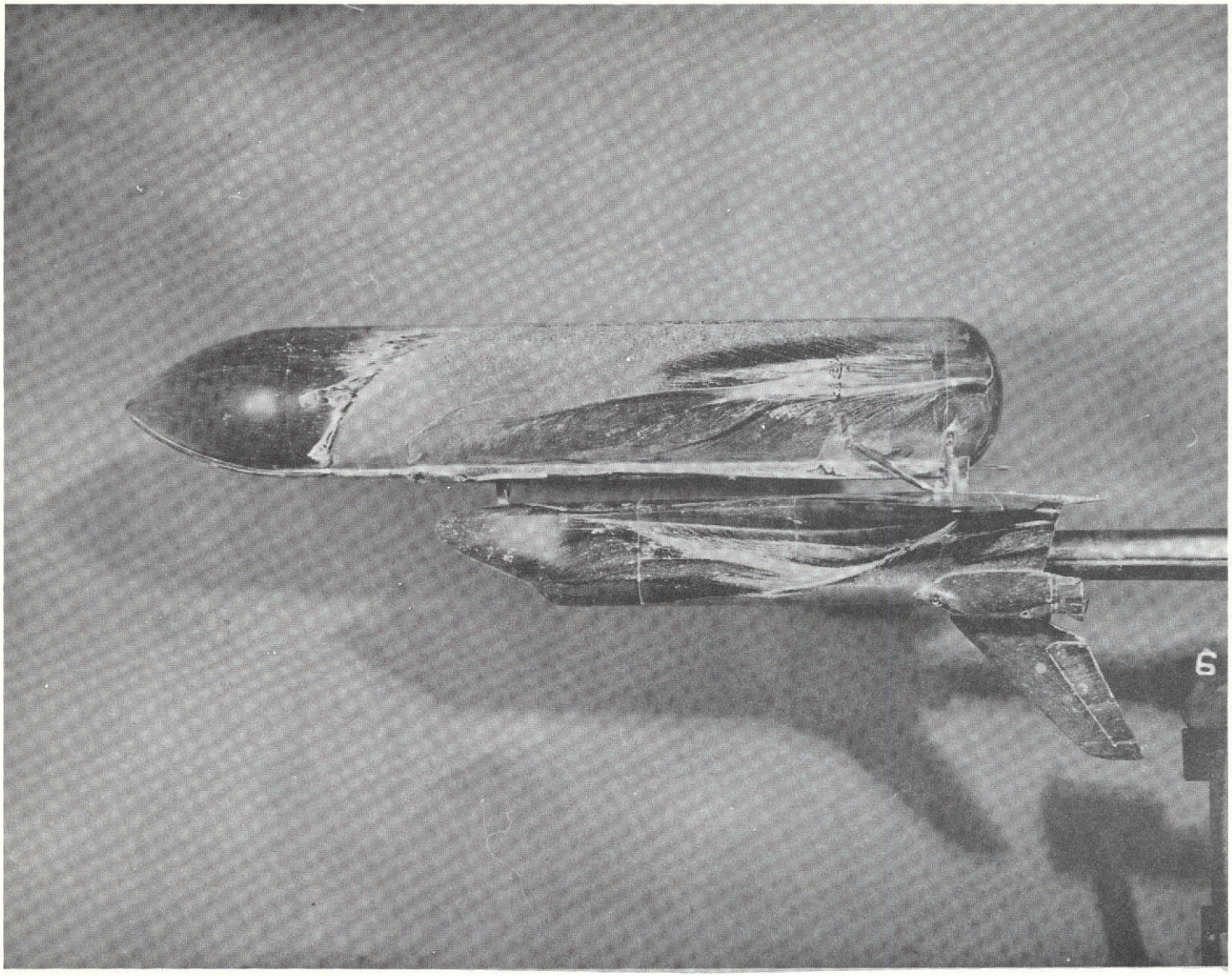


Figure 28. Run Number 6 View Right side

$\alpha = 0°$, $\beta = 2°$ Configuration Mated

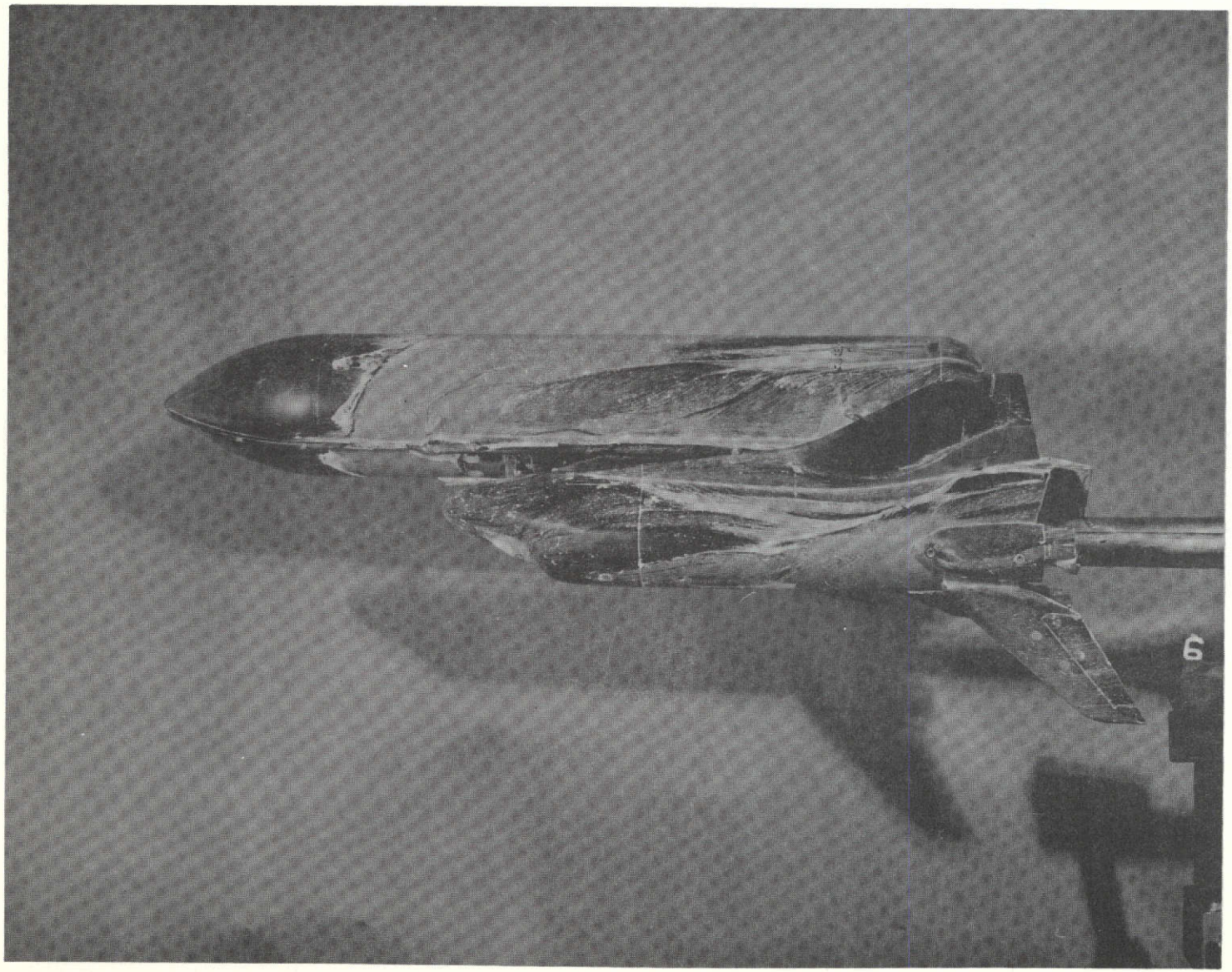


Figure 29. Run Number 6 View Upper right side

$\alpha = 0°$, $\beta \mp 2°$ Configuration Mated

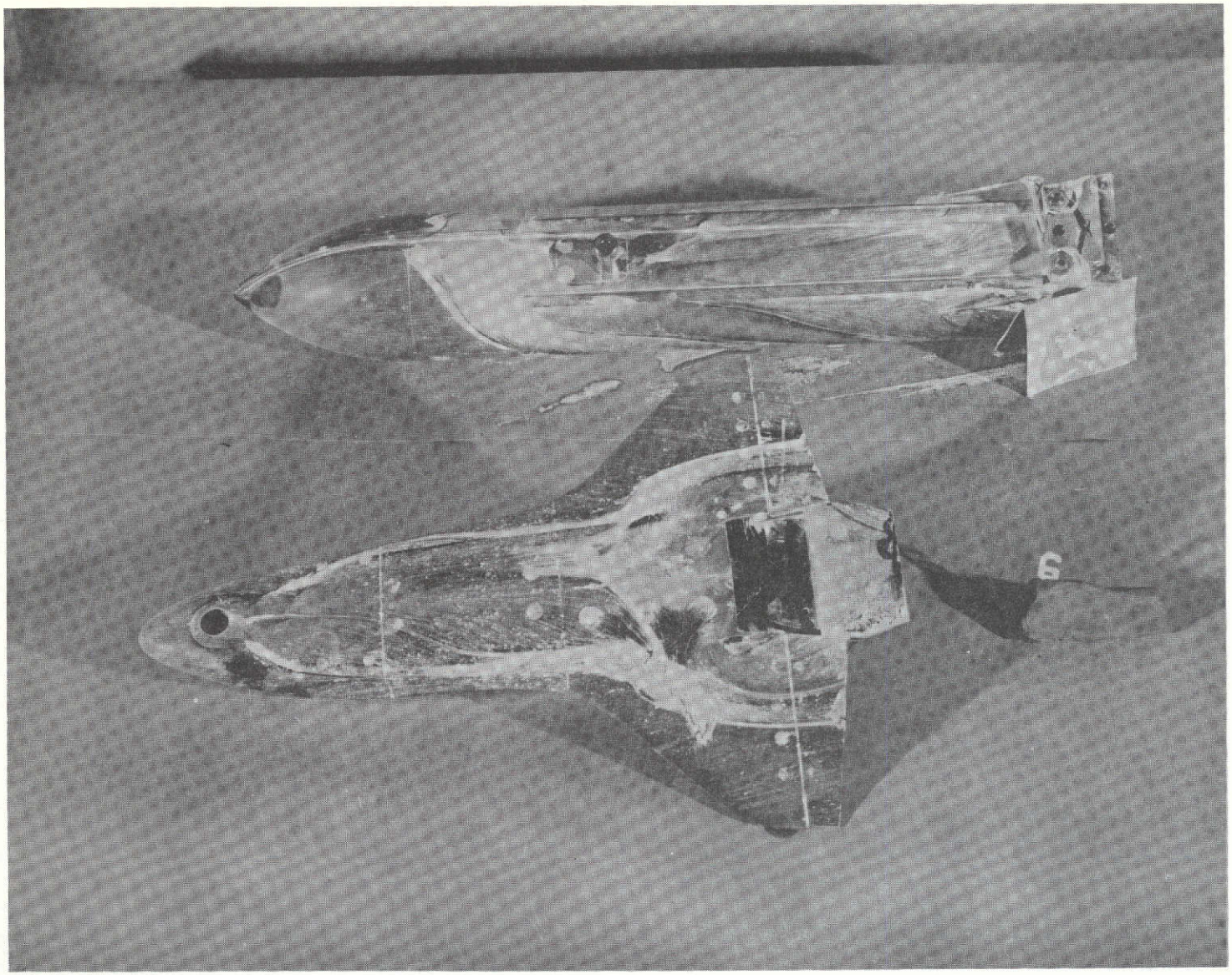


Figure 30. Run Number 6 View Interference regions

$\alpha = 0°$, $\beta = 2°$ Configuration Mated

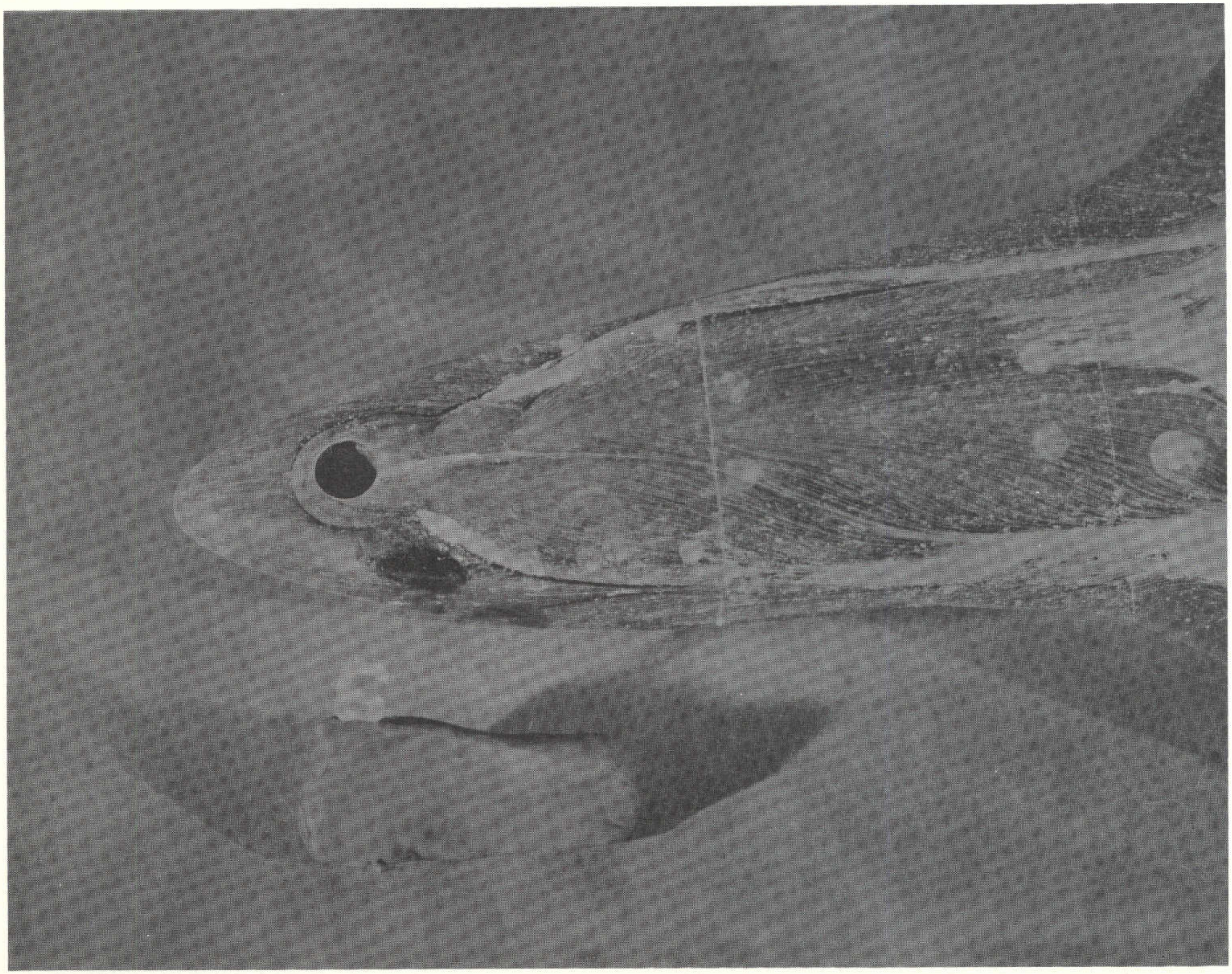


Figure 31. Run Number 6 View Orbiter forward bottom

$\alpha = 0°$, $\beta = 2°$ Configuration Mated

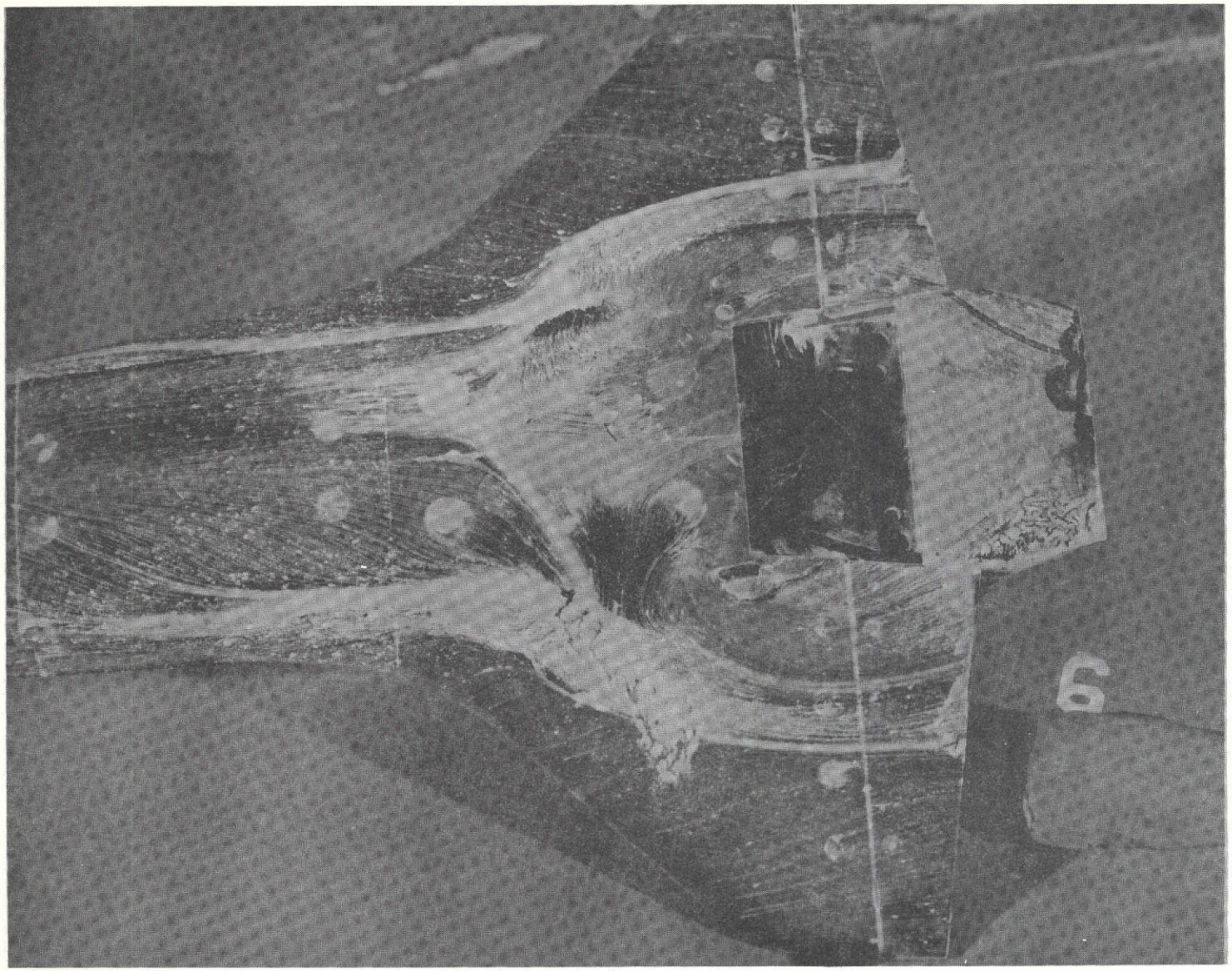


Figure 32. Run Number 6 View Orbiter rear bottom

$\alpha = 0°$, $\beta = 2°$ Configuration Mated

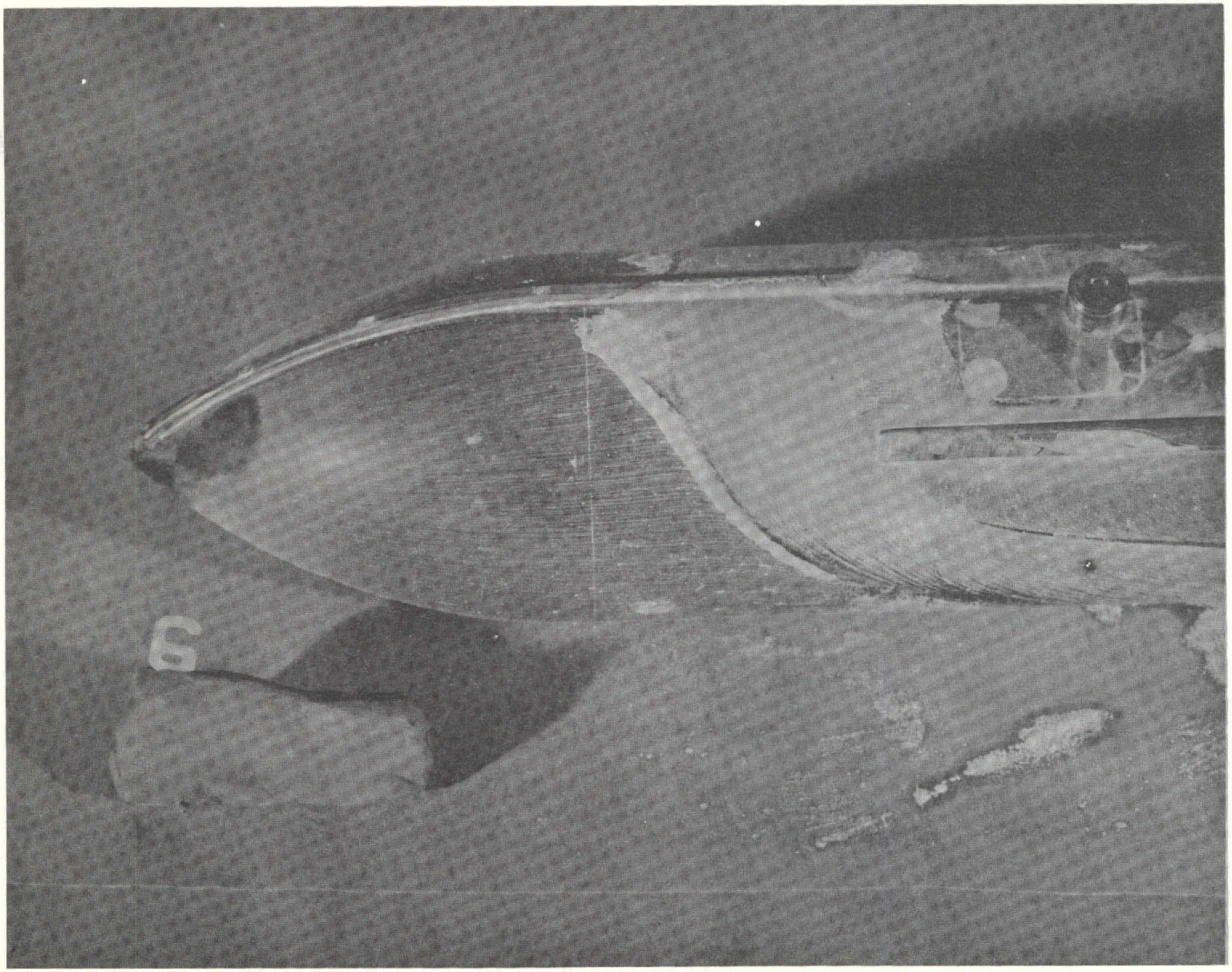


Figure 33. Run Number 6 View Tank forward top

$\alpha = 0°$, $\beta = 2°$ Configuration Mated

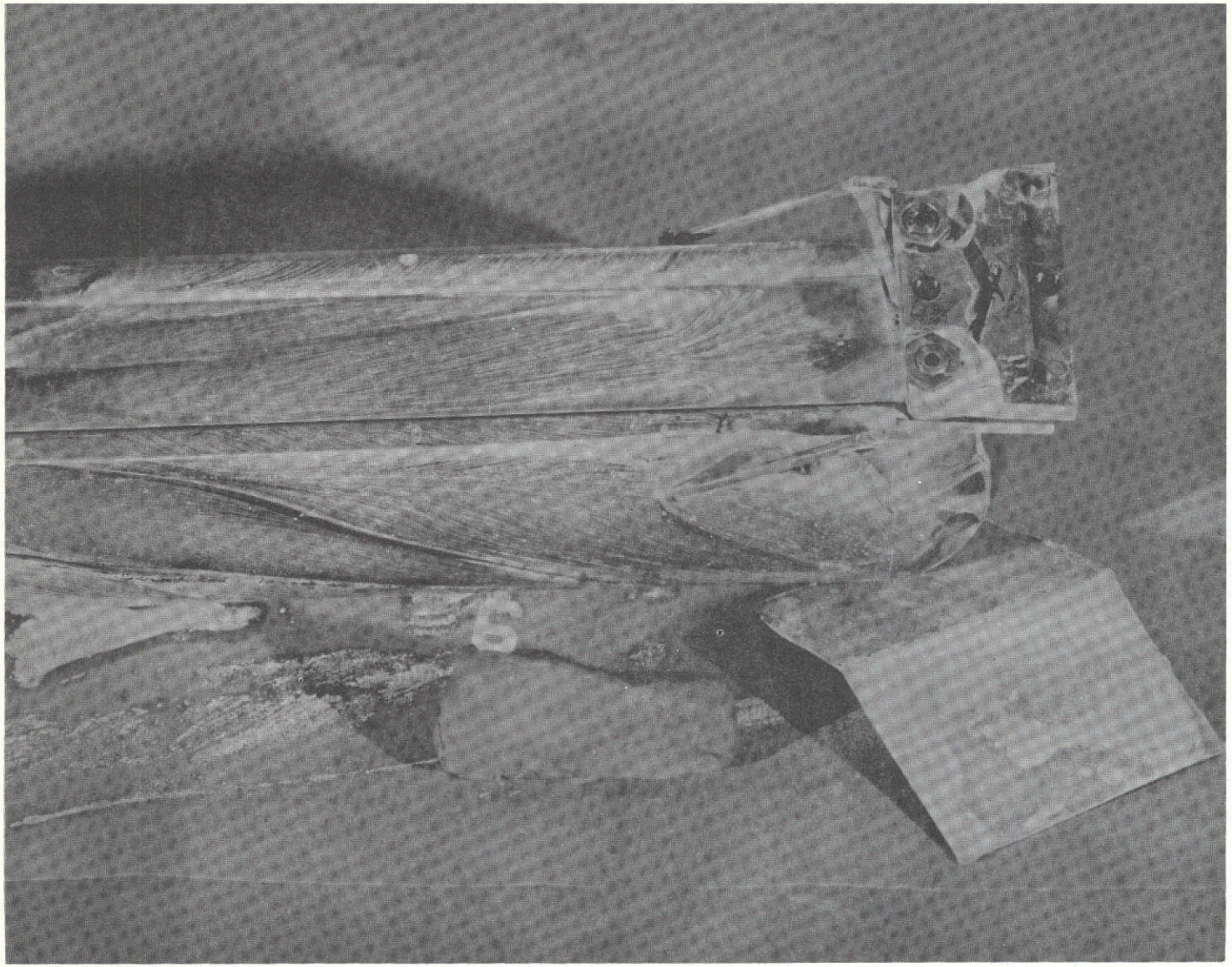


Figure 34. Run Number 6 View Tank rear top

$\alpha = 0°$, $\beta = 2°$ Configuration Mated

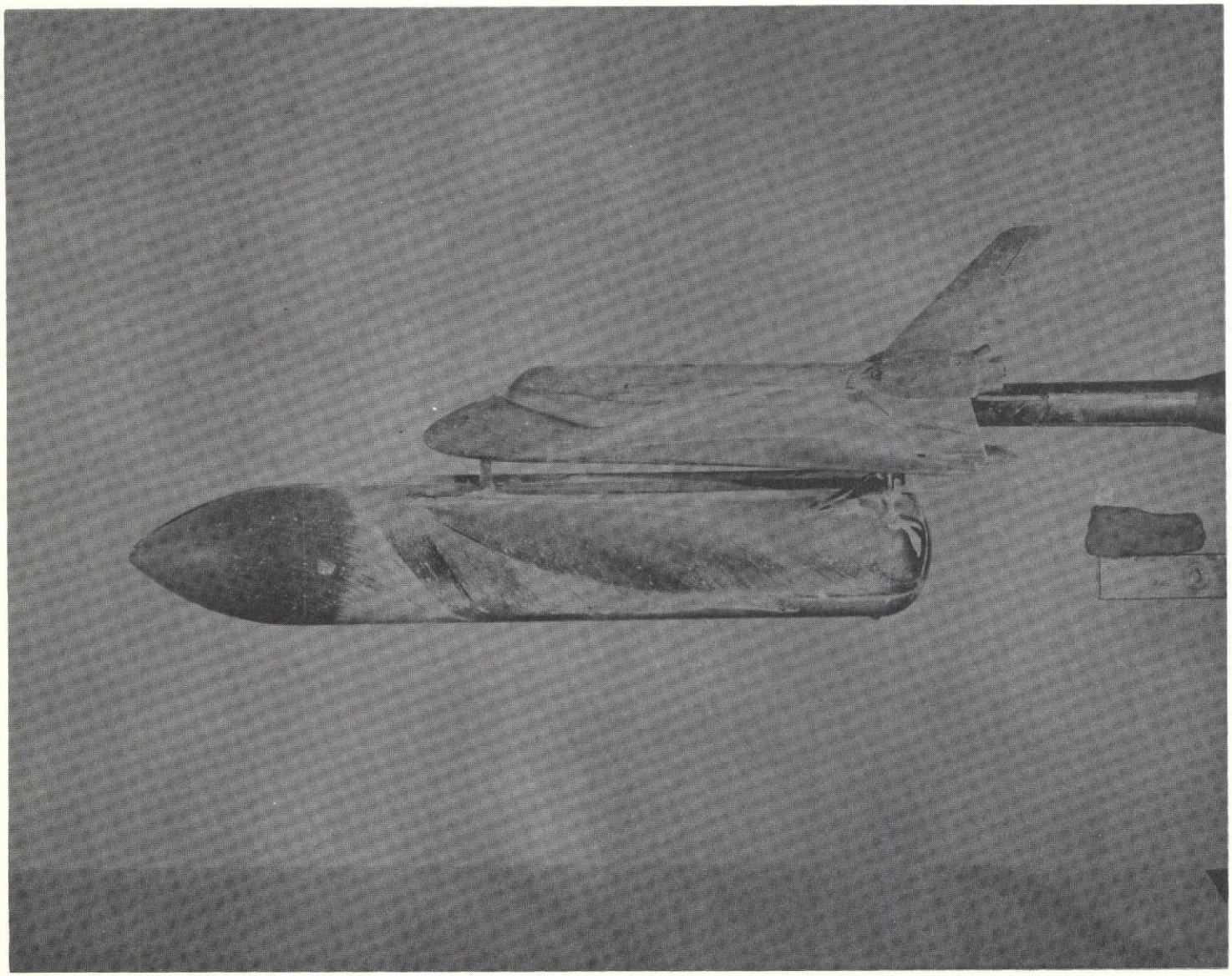


Figure 35. Run Number 8 View Left side

$\alpha = -5°$, $\beta = 2°$ Configuration Mated

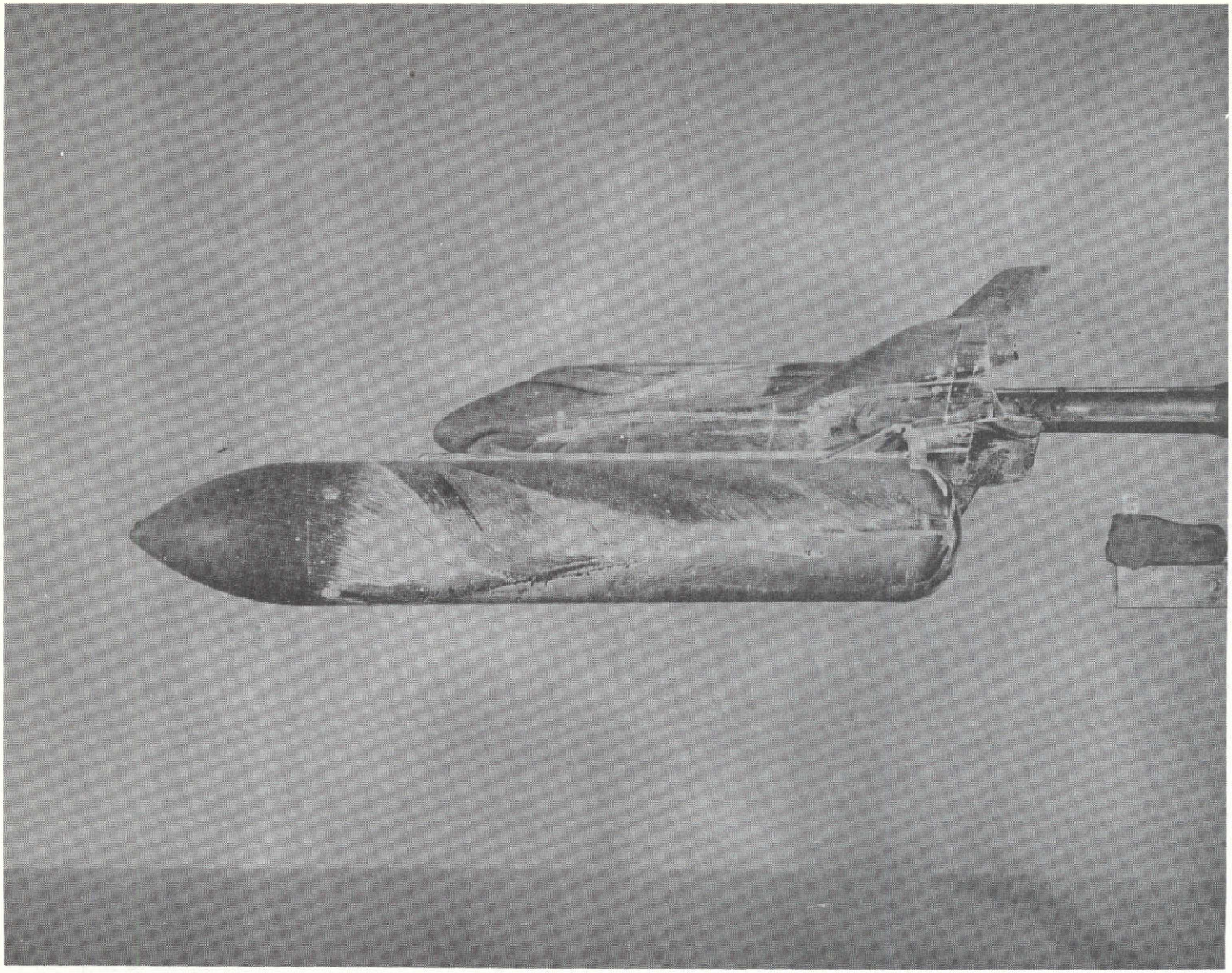


Figure 36. Run Number 8 View Lower left side

$\alpha = -5°$, $\beta = 2°$ Configuration Mated

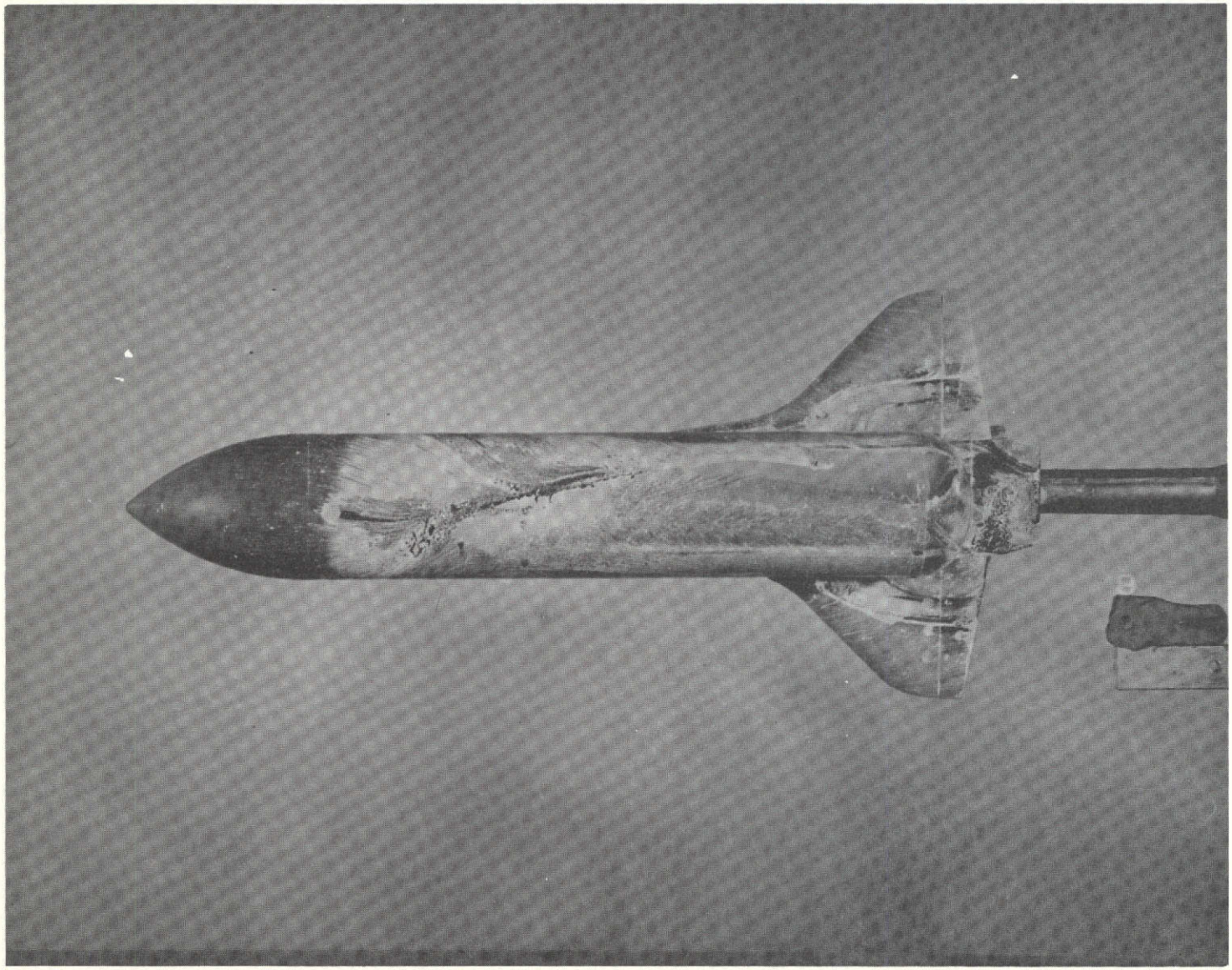


Figure 37. Run Number 8 View Bottom

α = -5°, β = 2° Configuration Mated

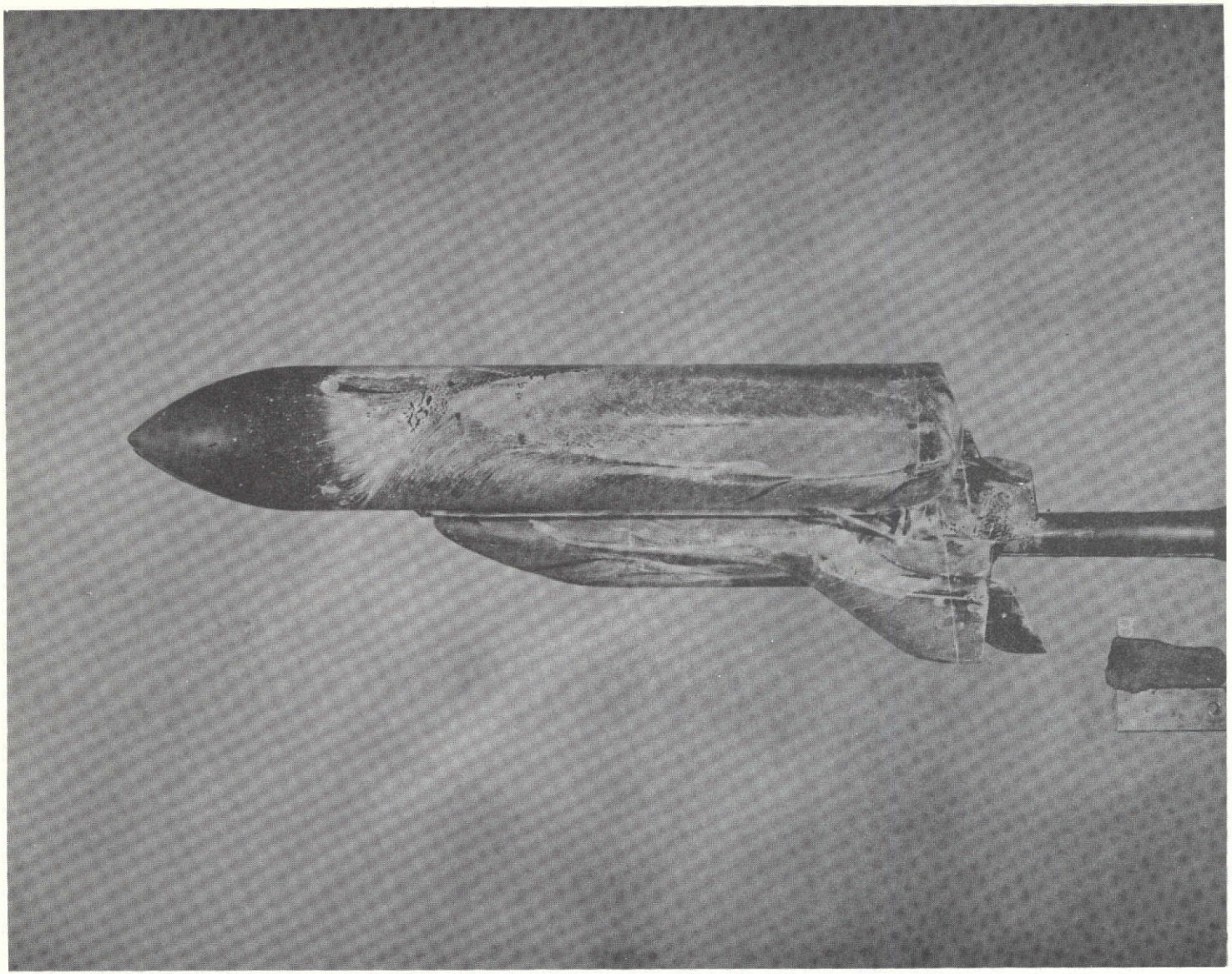


Figure 38. Run Number 8 View Lower right side

α = -5°, β = 2° Configuration Mated

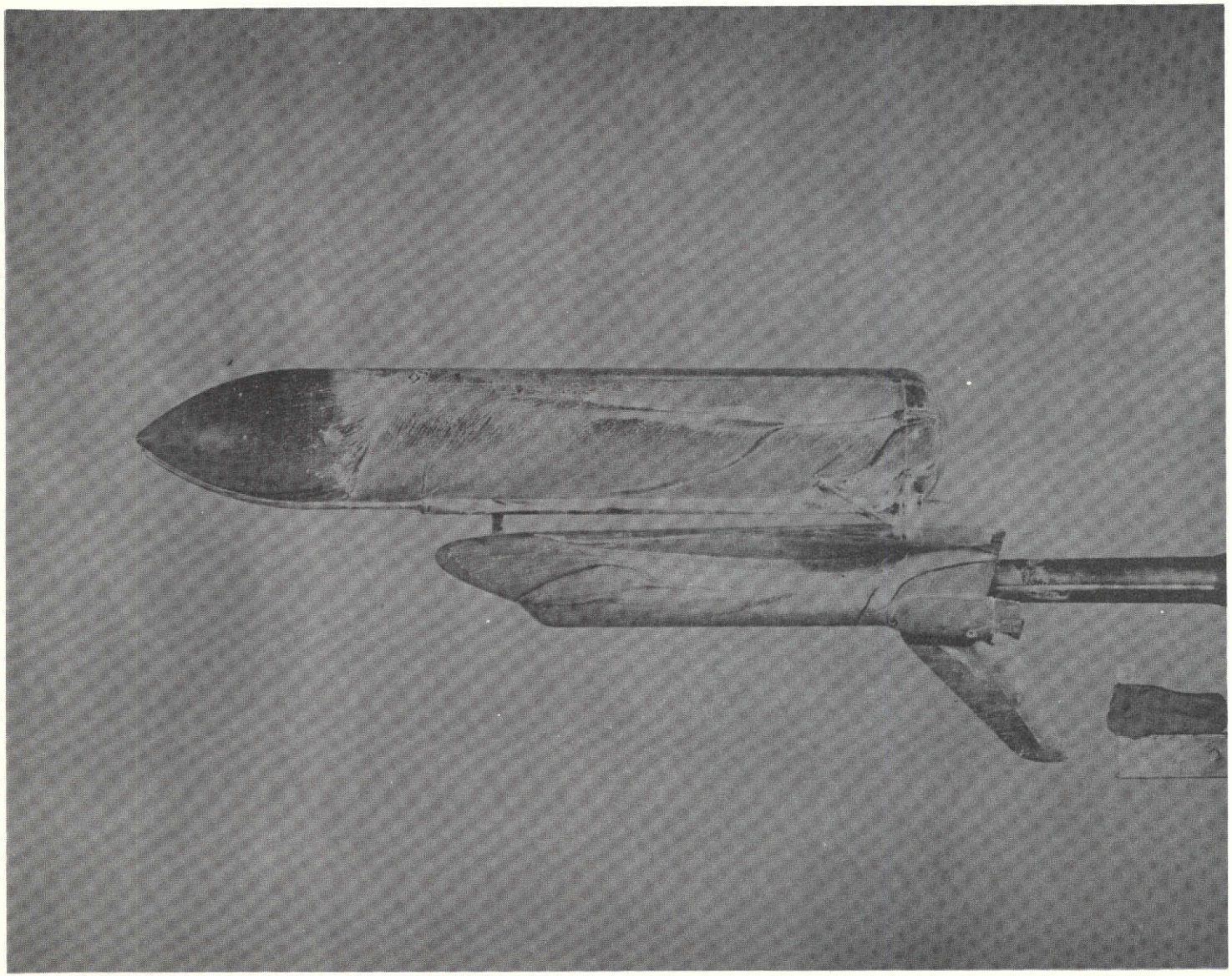


Figure 39. Run Number 8 View Right side

α = -5°, β = 2° Configuration Mated

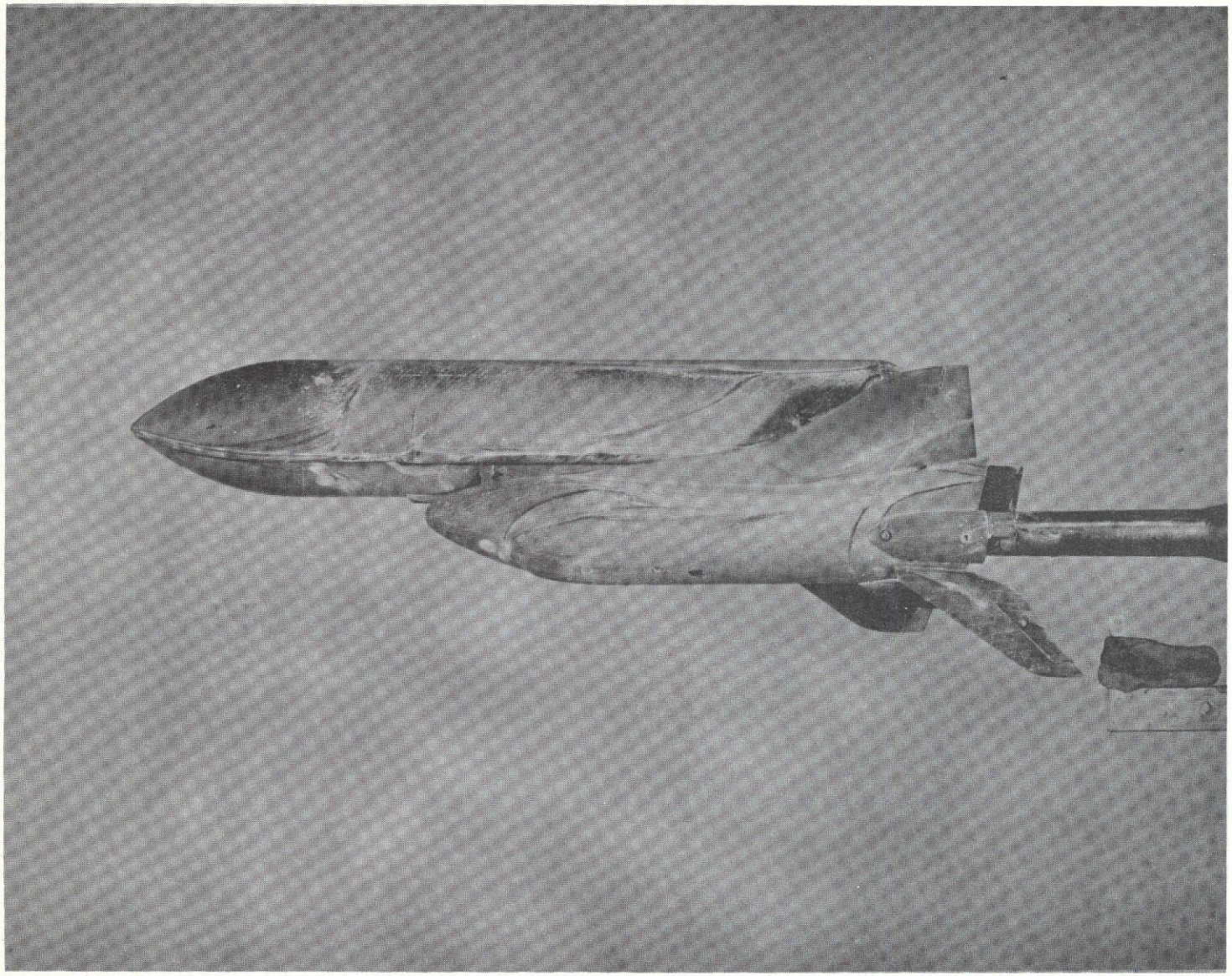


Figure 40. Run Number 8 View Upper right side

α = -5°, β = 2° Configuration Mated

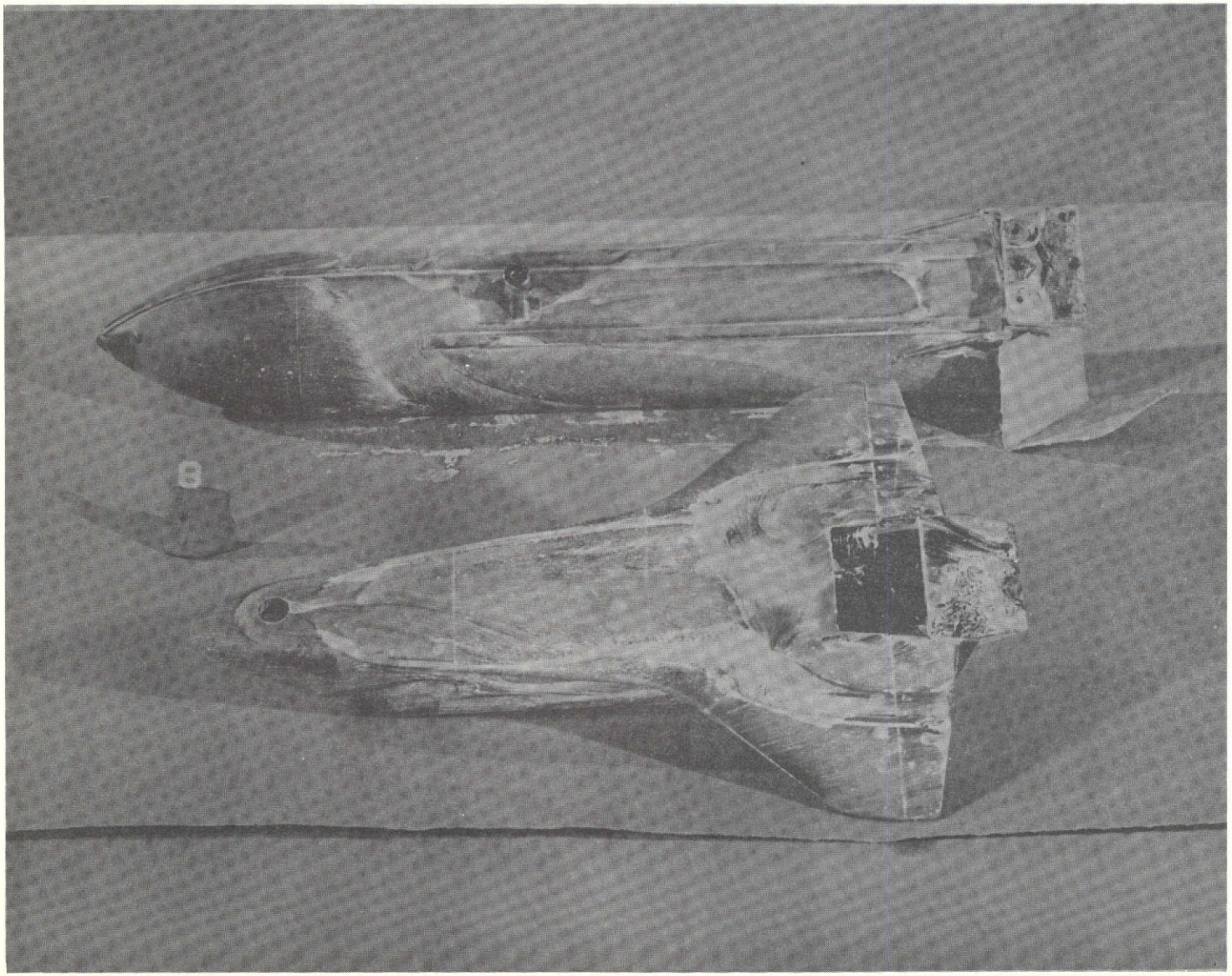


Figure 41. Run Number 8 View Interference region

α = -5°, β = 2° Configuration Mated

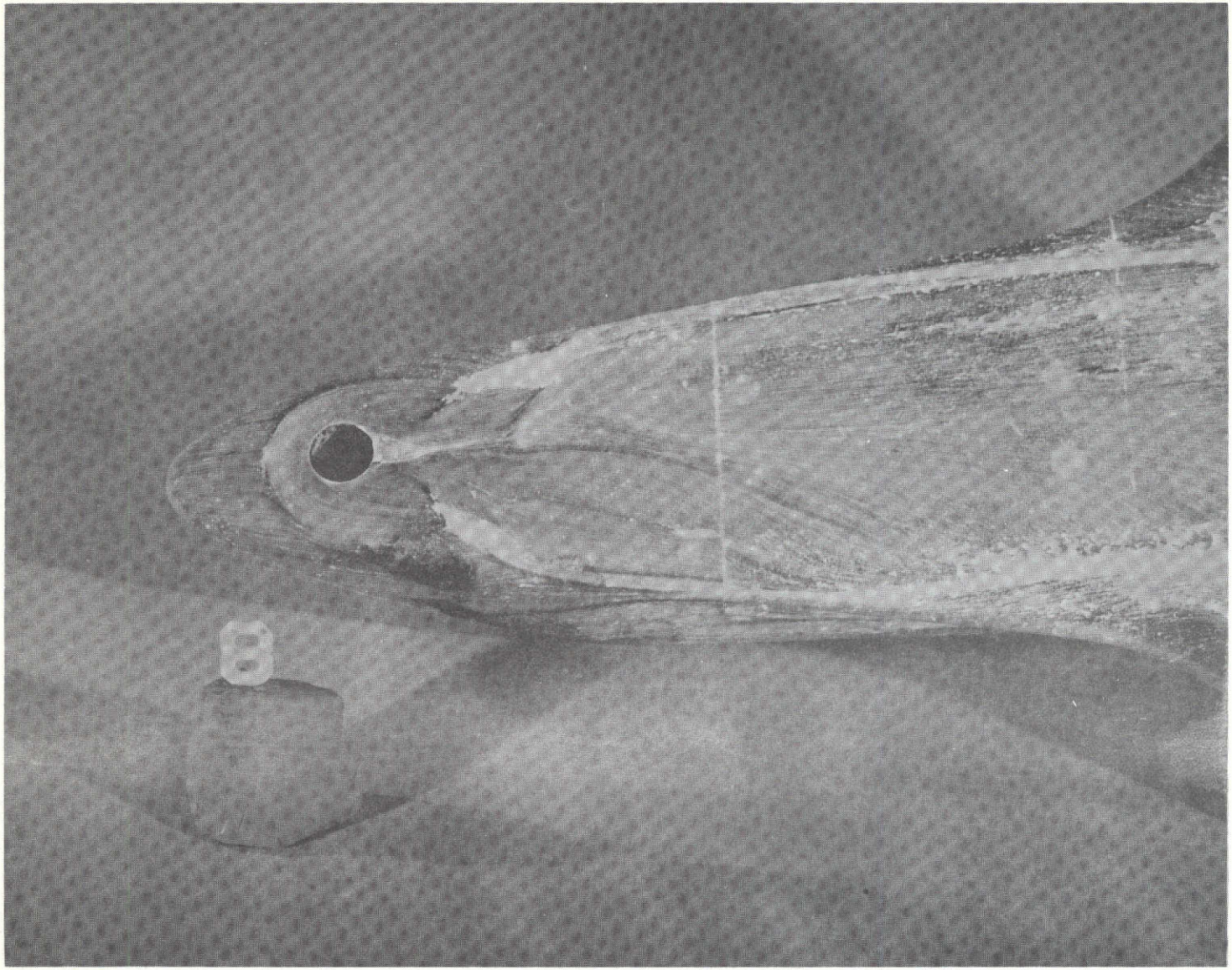


Figure 42. Run Number 8 View Orbiter forward bottom
$\alpha = -5°$, $\beta = 2°$ Configuration Mated

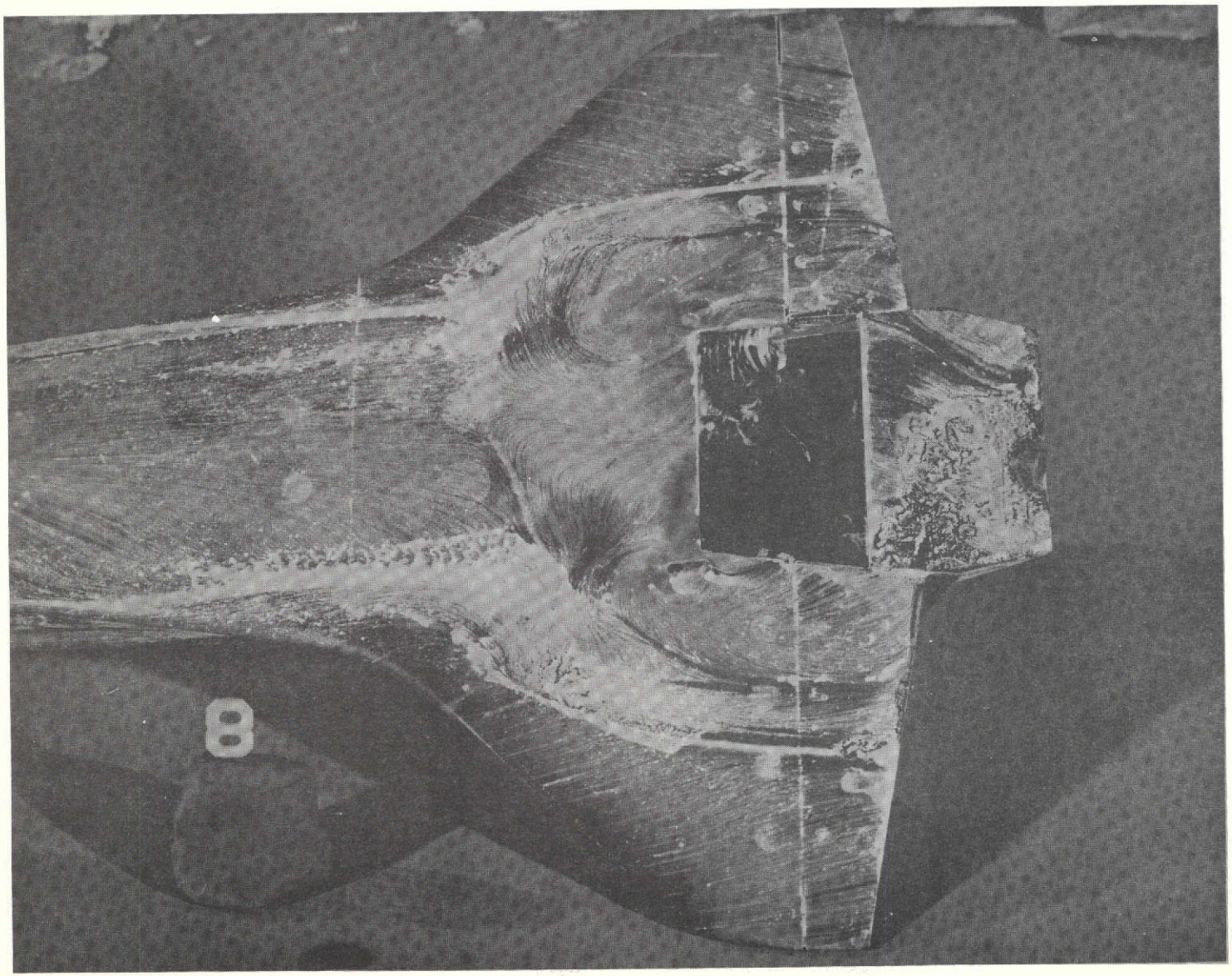


Figure 43. Run Number 8 View Orbiter rear bottom

α = -5°, β = 2° Configuration Mated

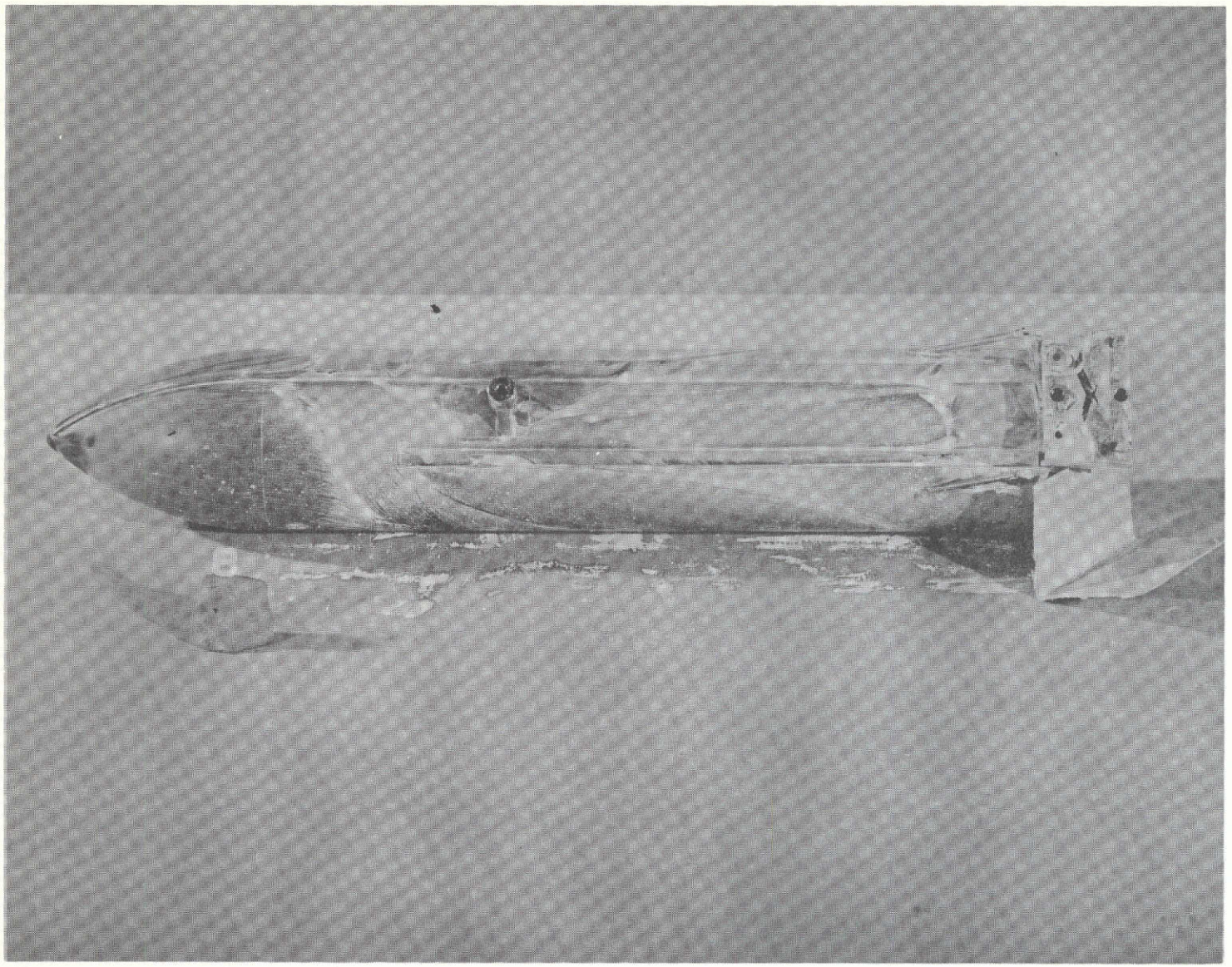


Figure 44. Run Number 8 View Tank top

$\alpha = -5°$, $\beta = 2°$ Configuration Mated

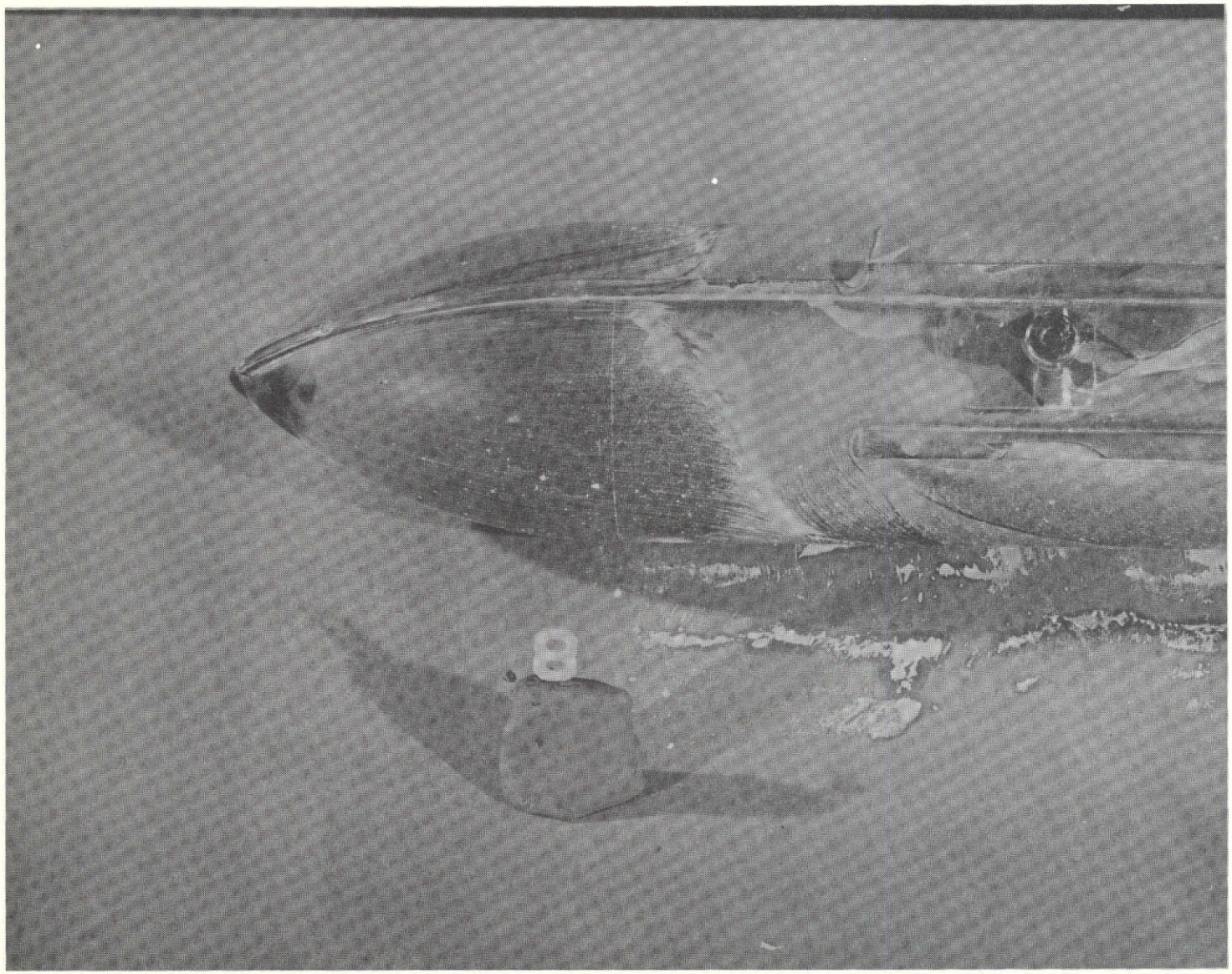


Figure 45. Run Number 8 View Tank Forward Top
$\alpha = -5°$, $\beta = 2°$ Configuration Mated

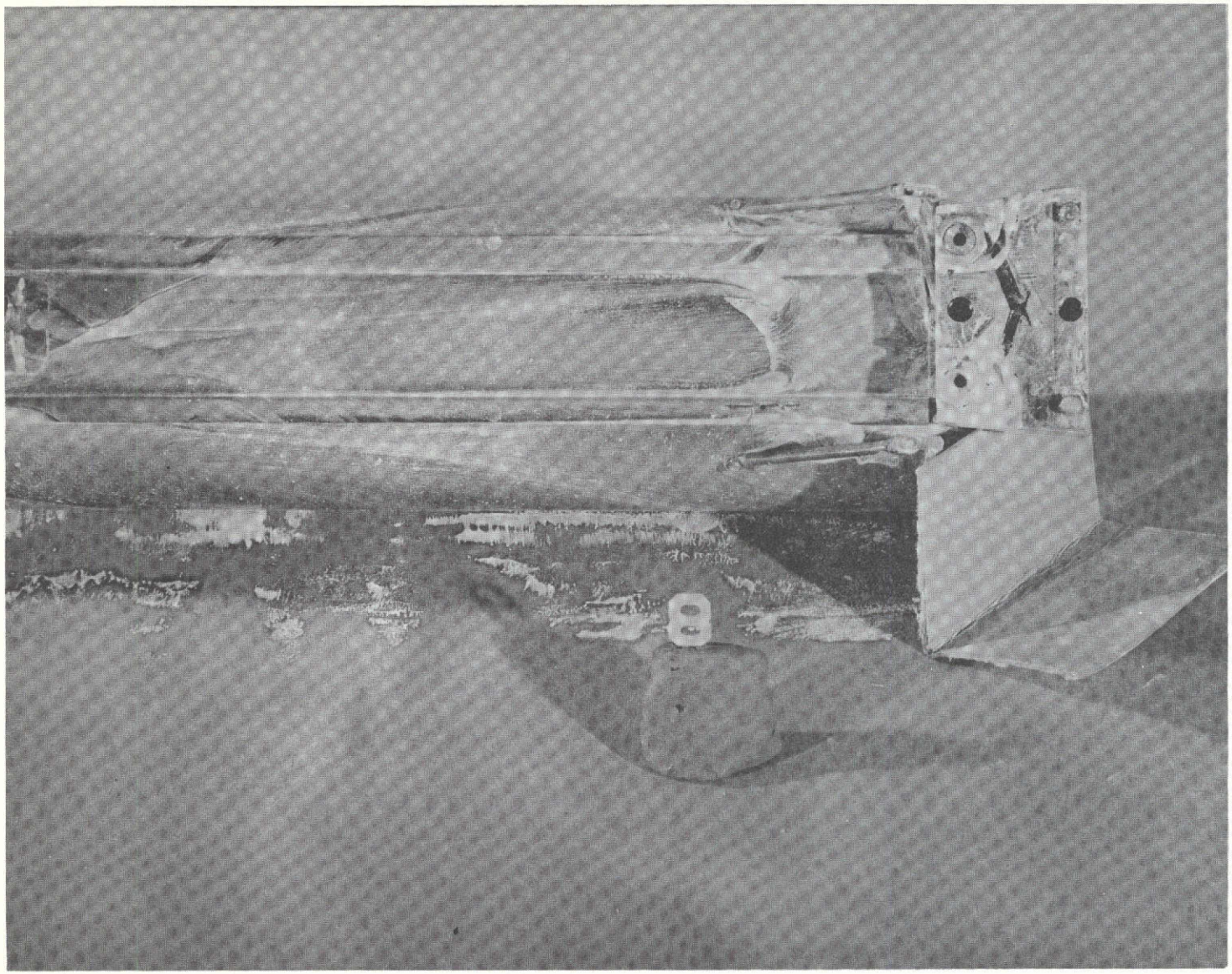


Figure 46. Run Number 8 View Tank rear top

$\alpha = -5°$, $\beta = 2°$ Configuration Mated

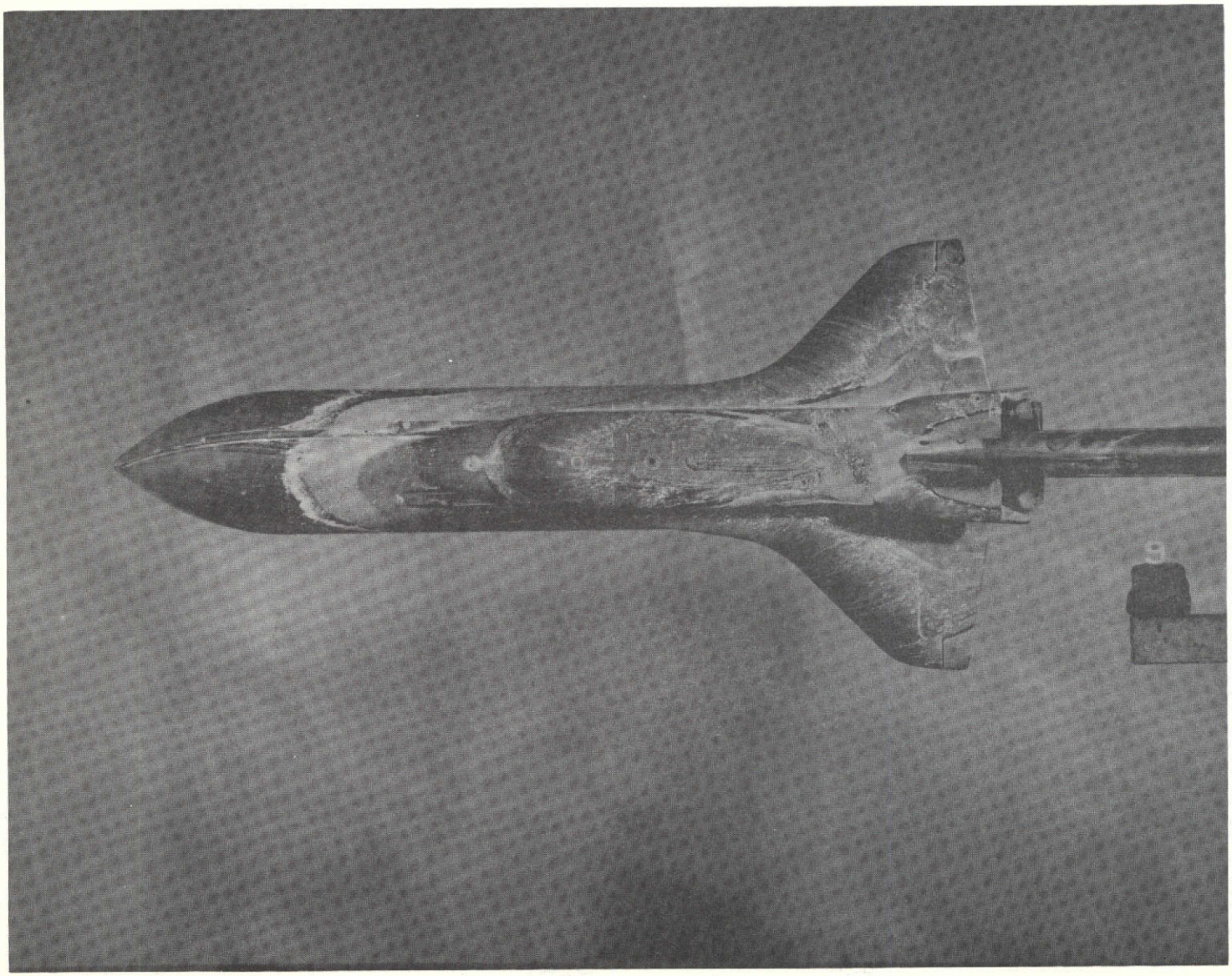


Figure 47. Run Number 9 View Top

$\alpha = 5°$, $\beta = 0°$ Configuration Mated

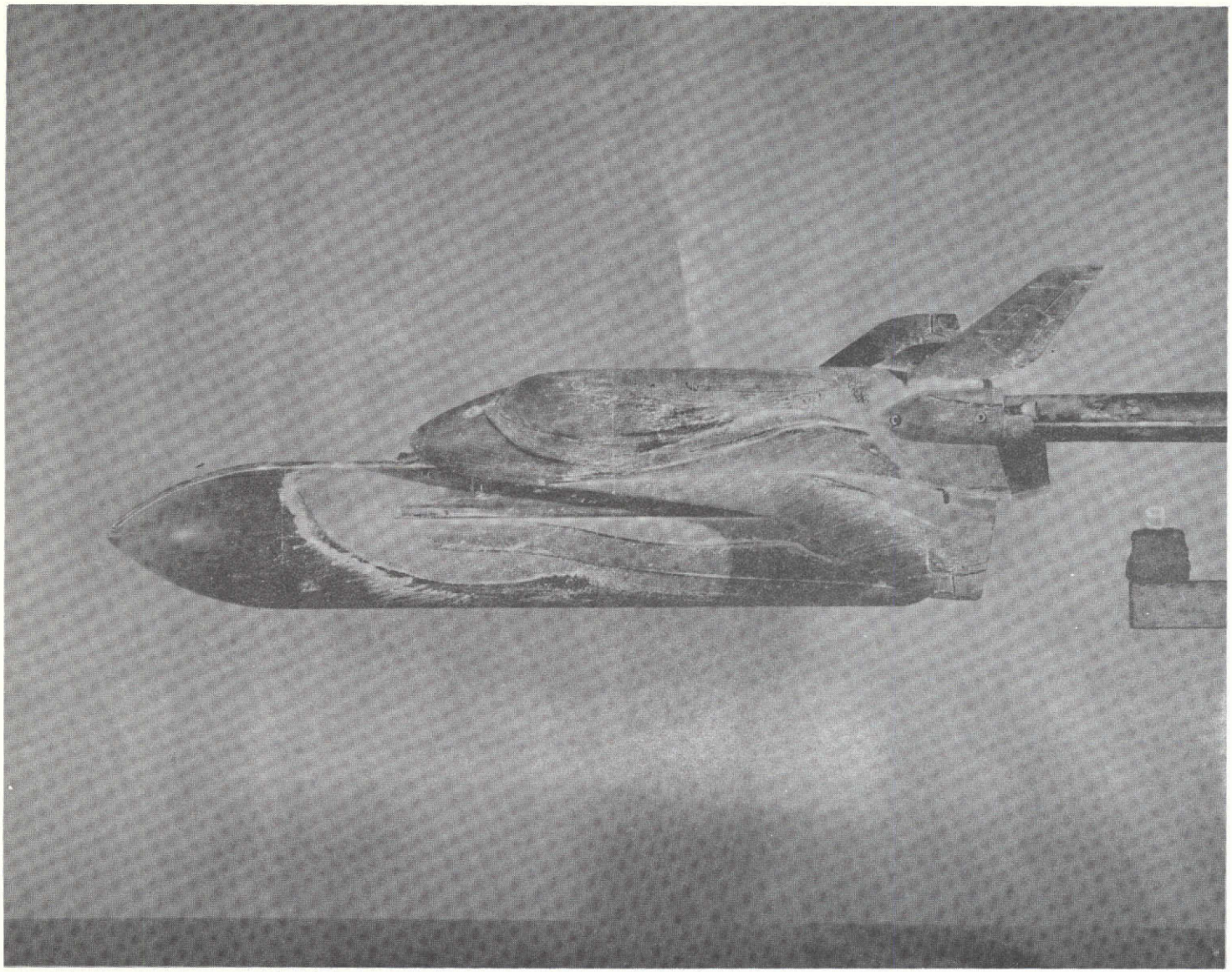


Figure 48. Run Number 9 View Upper left side

$\alpha = 5°$, $\beta = 0°$ Configuration Mated

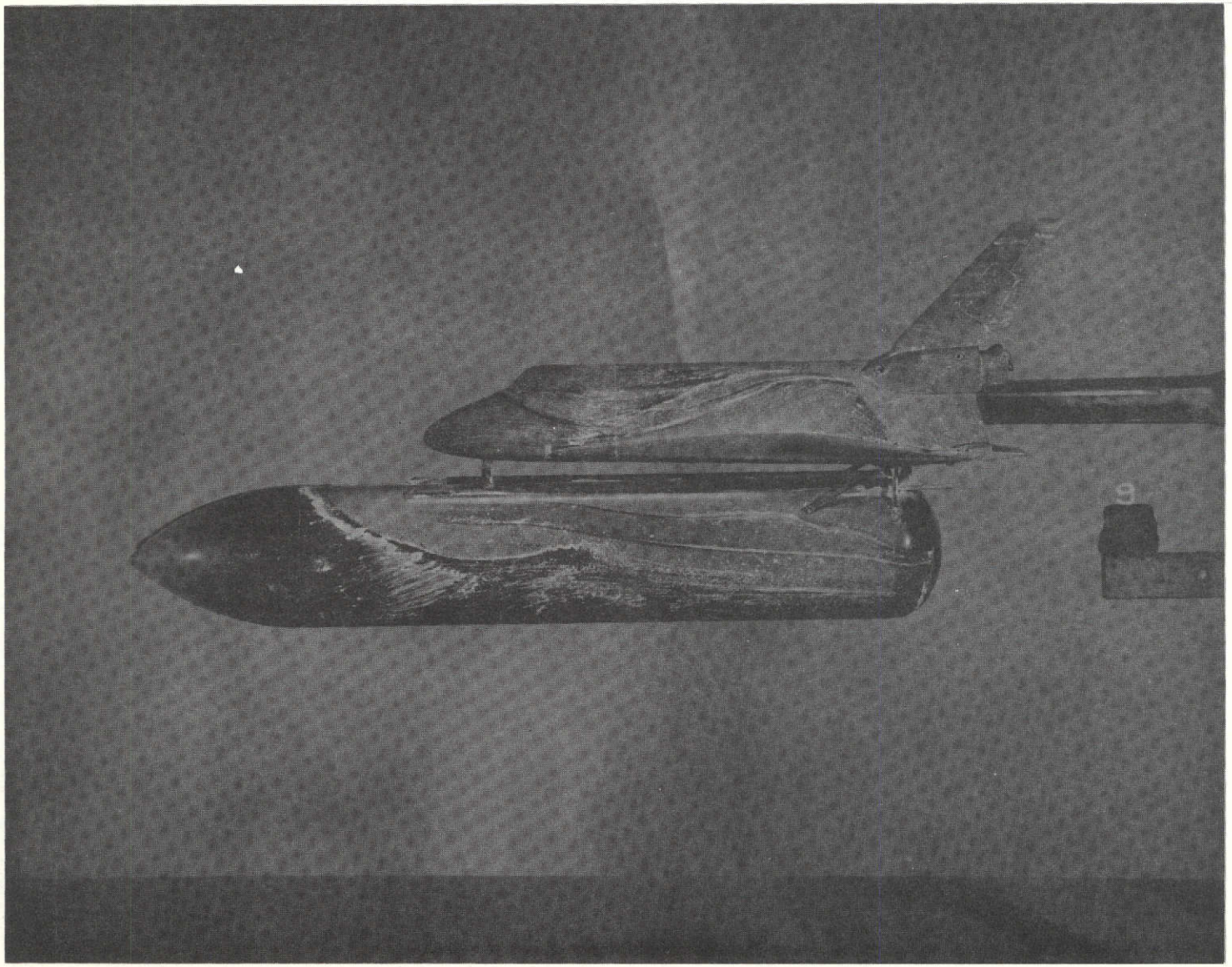


Figure 49. Run Number 9 View Left side

$\alpha = 5°$, $\beta = 0°$ Configuration Mated

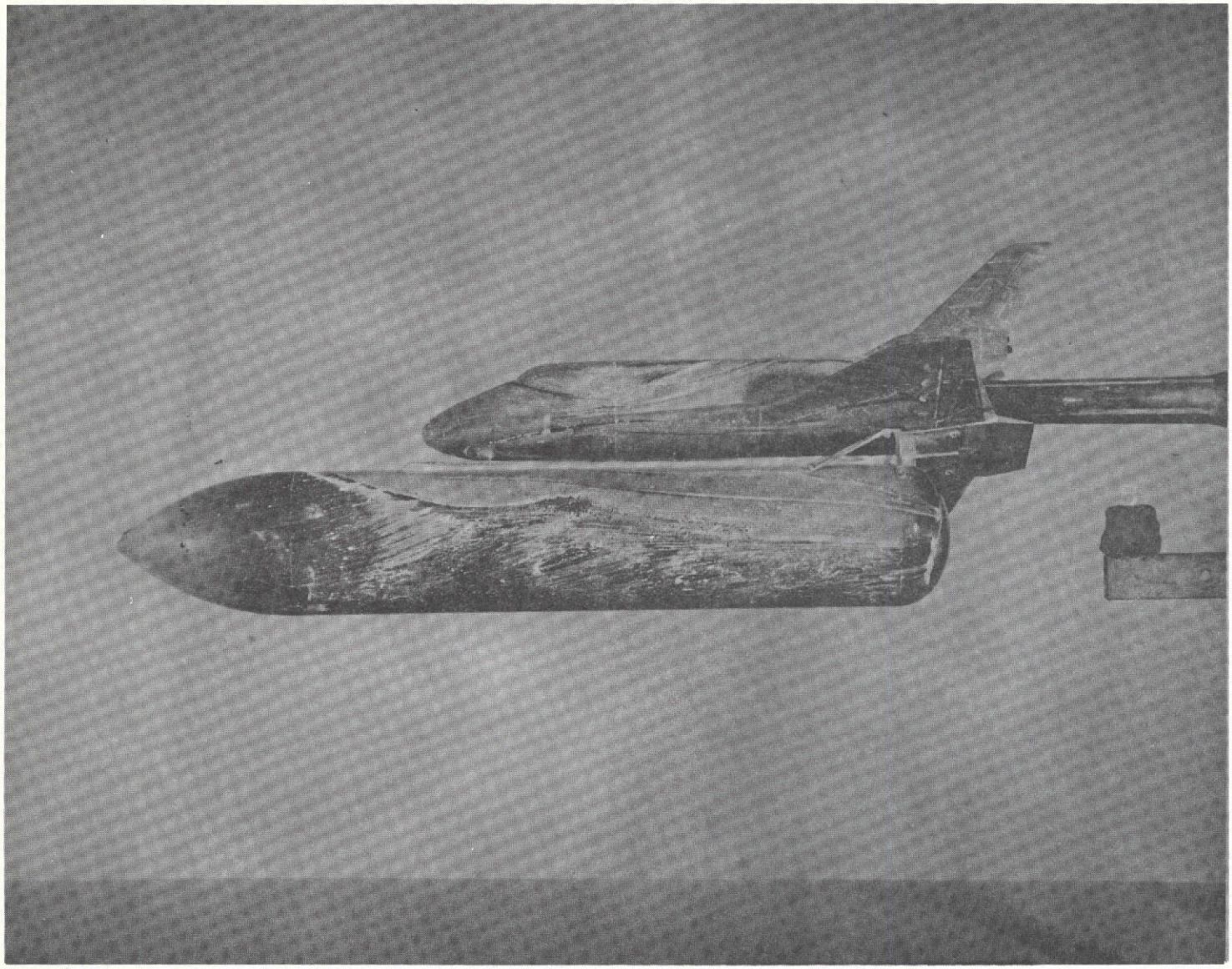


Figure 50. Run Number 9 View Lower left side

$\alpha = 5°$, $\beta = 0°$ Configuration Mated

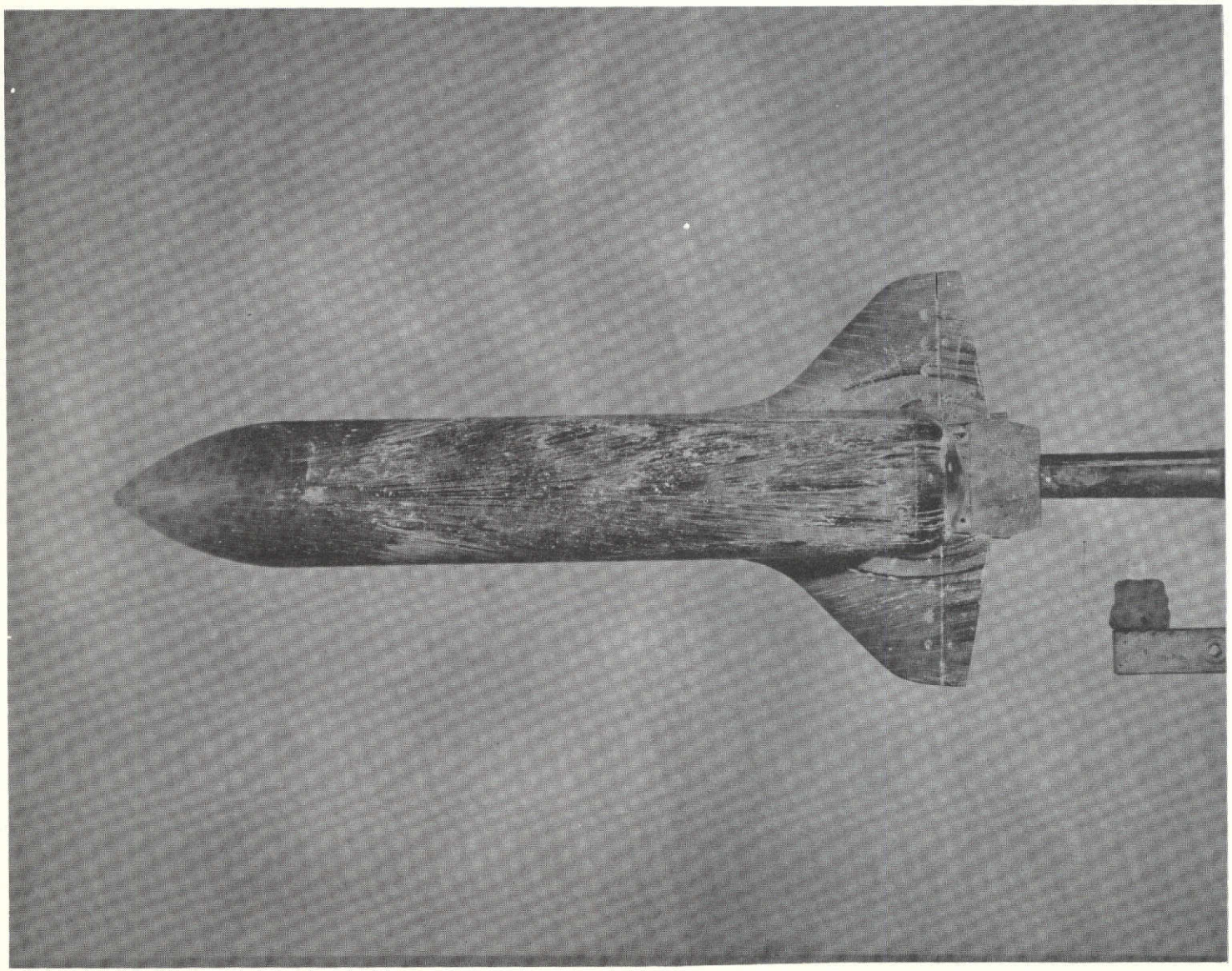


Figure 51. Run Number 9 View Bottom

$\alpha = 5°$, $\beta = 2°$, Configuration Mated

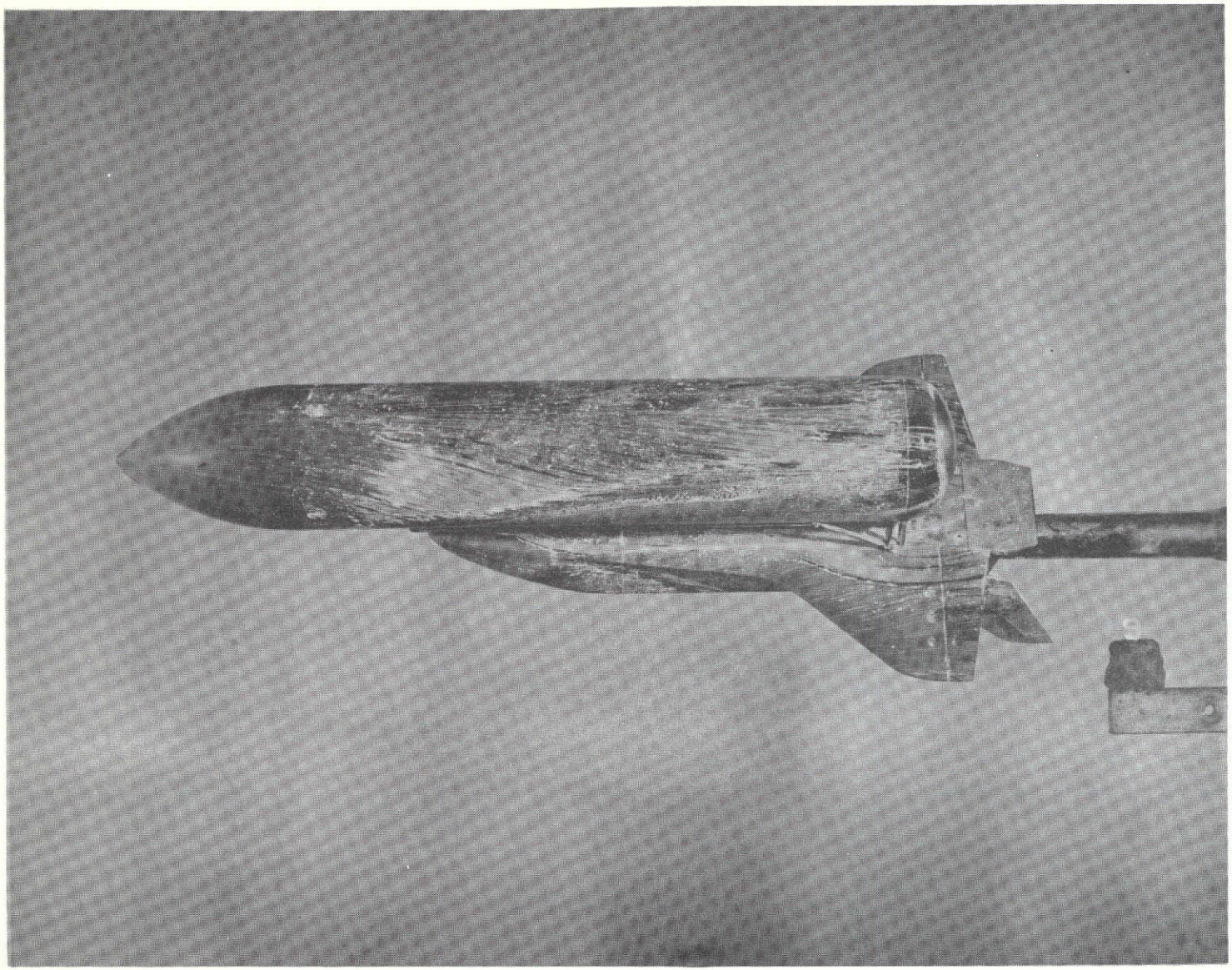


Figure 52. Run Number 9 View Lower right side

$\alpha = 5°$, $\beta = 0°$ Configuration Mated

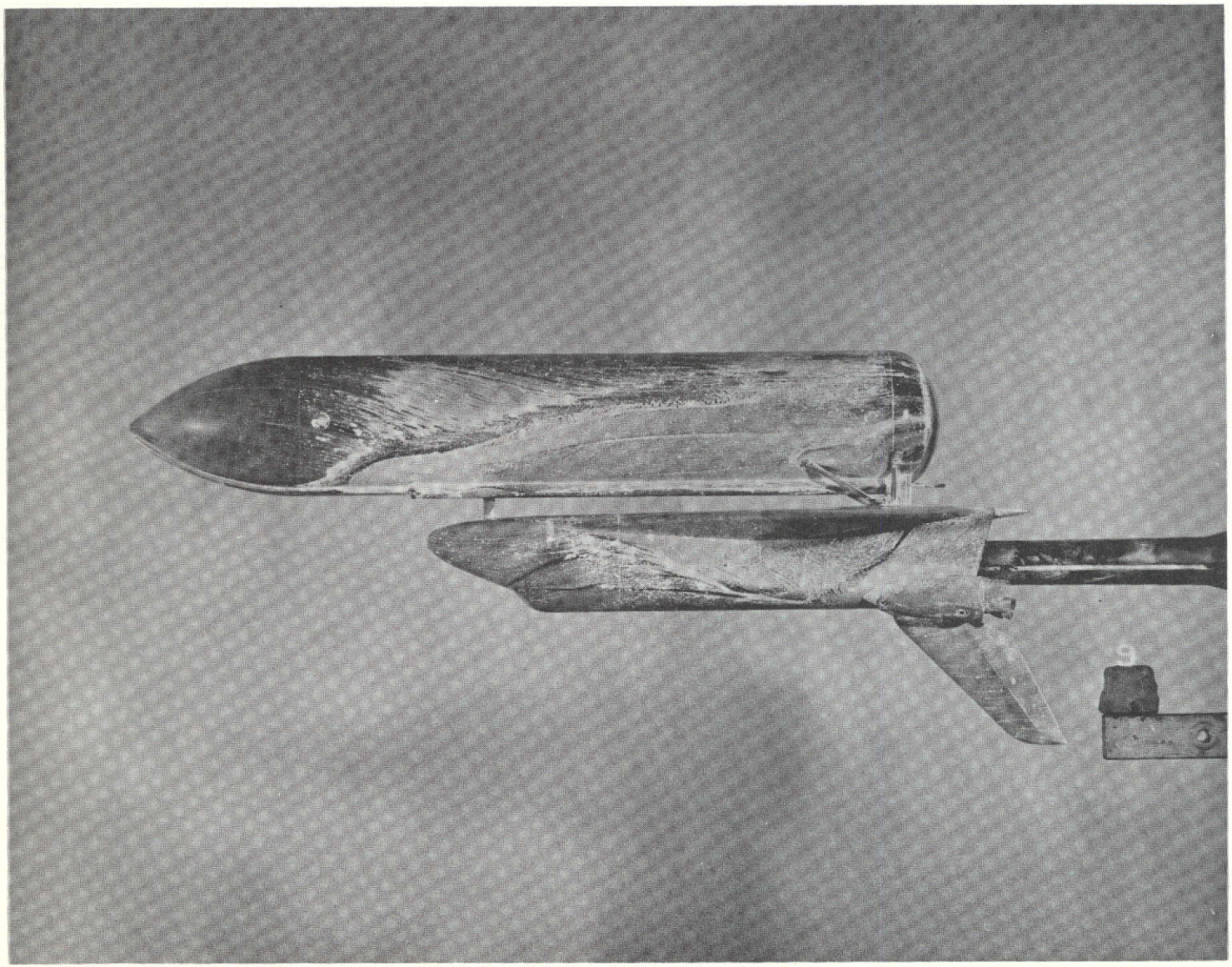


Figure 53. Run Number 9 View Right side

$\alpha = 5°$, $\beta = 0°$ Configuration Mated

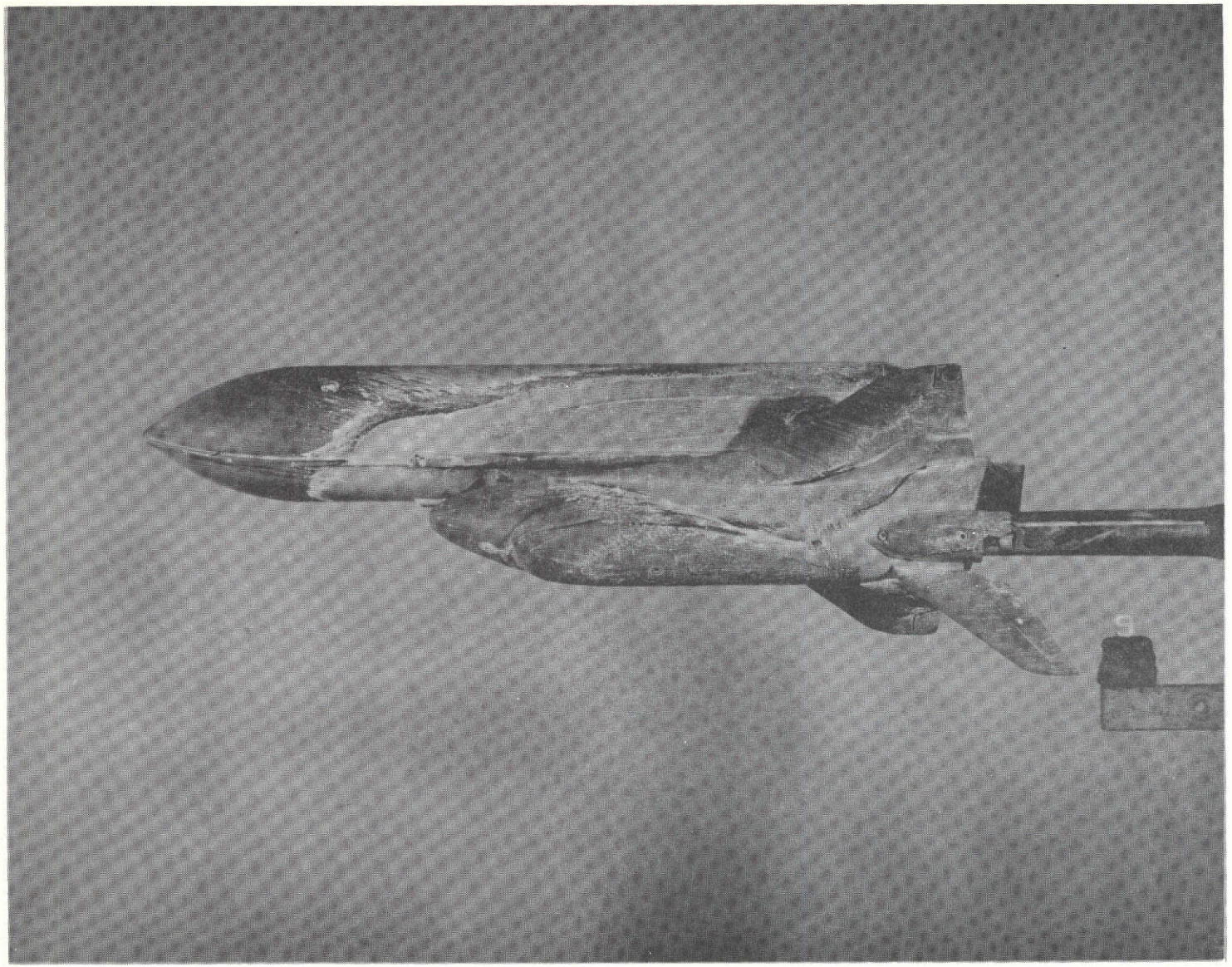


Figure 54. Run Number 9 View Upper right side

$\alpha = 5°$, $\beta = 0°$ Configuration Mated

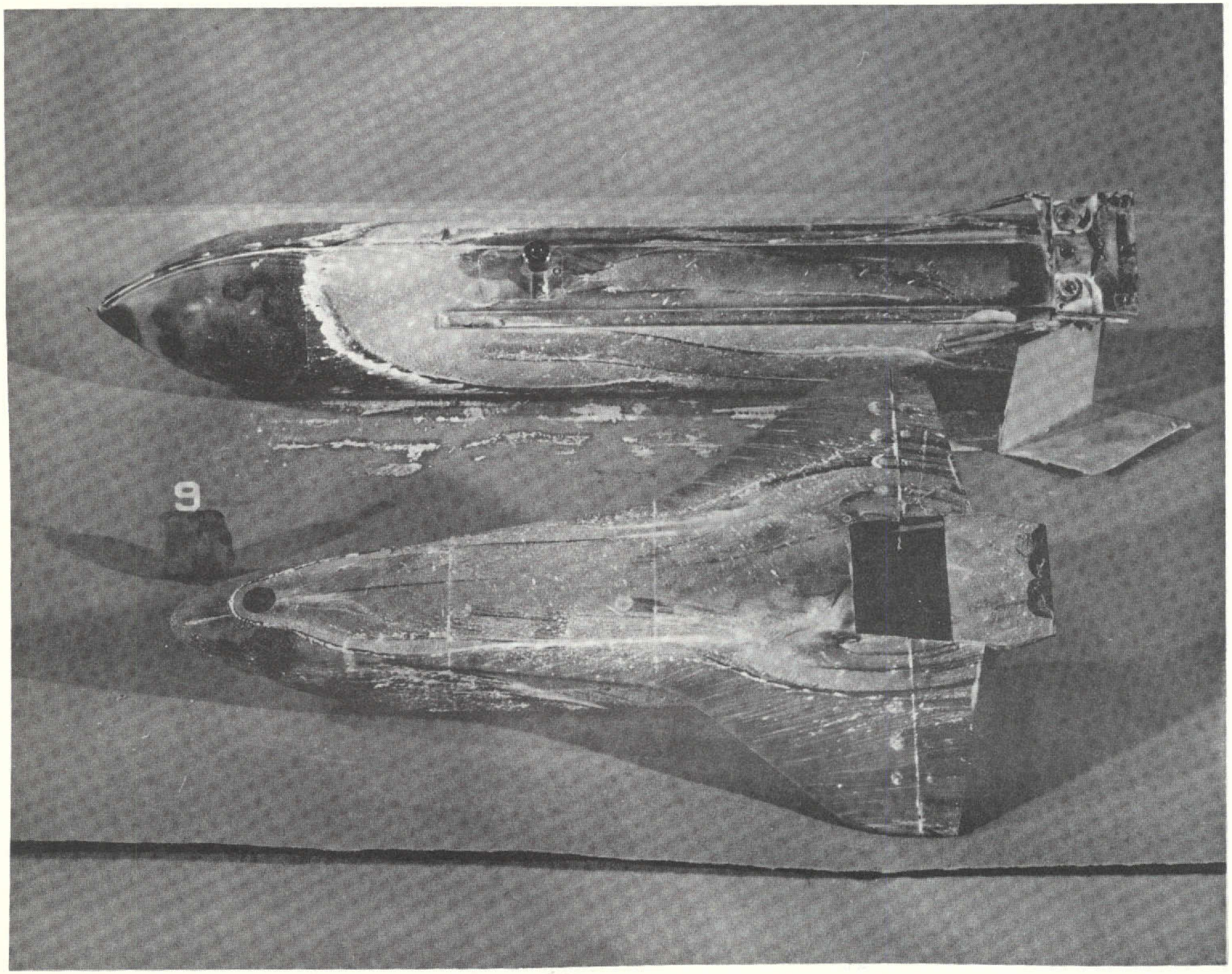


Figure 55. Run Number 9 View Interference region

$\alpha = 5°$, $\beta = 0°$ Configuration Mated

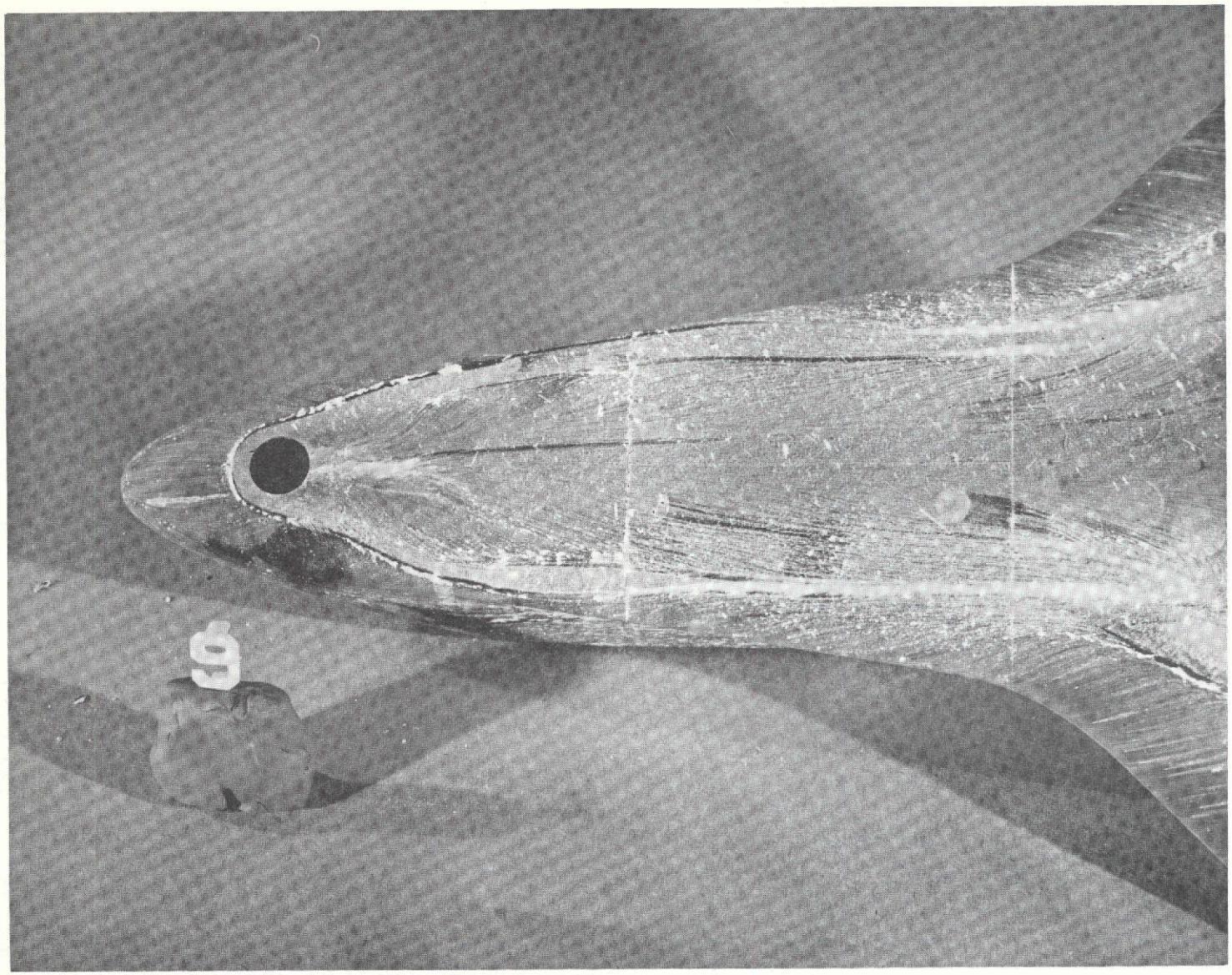


Figure 56. Run Number 9 View Orbiter forward bottom

$\alpha = 5°$, $\beta = 0°$ Configuration Mated

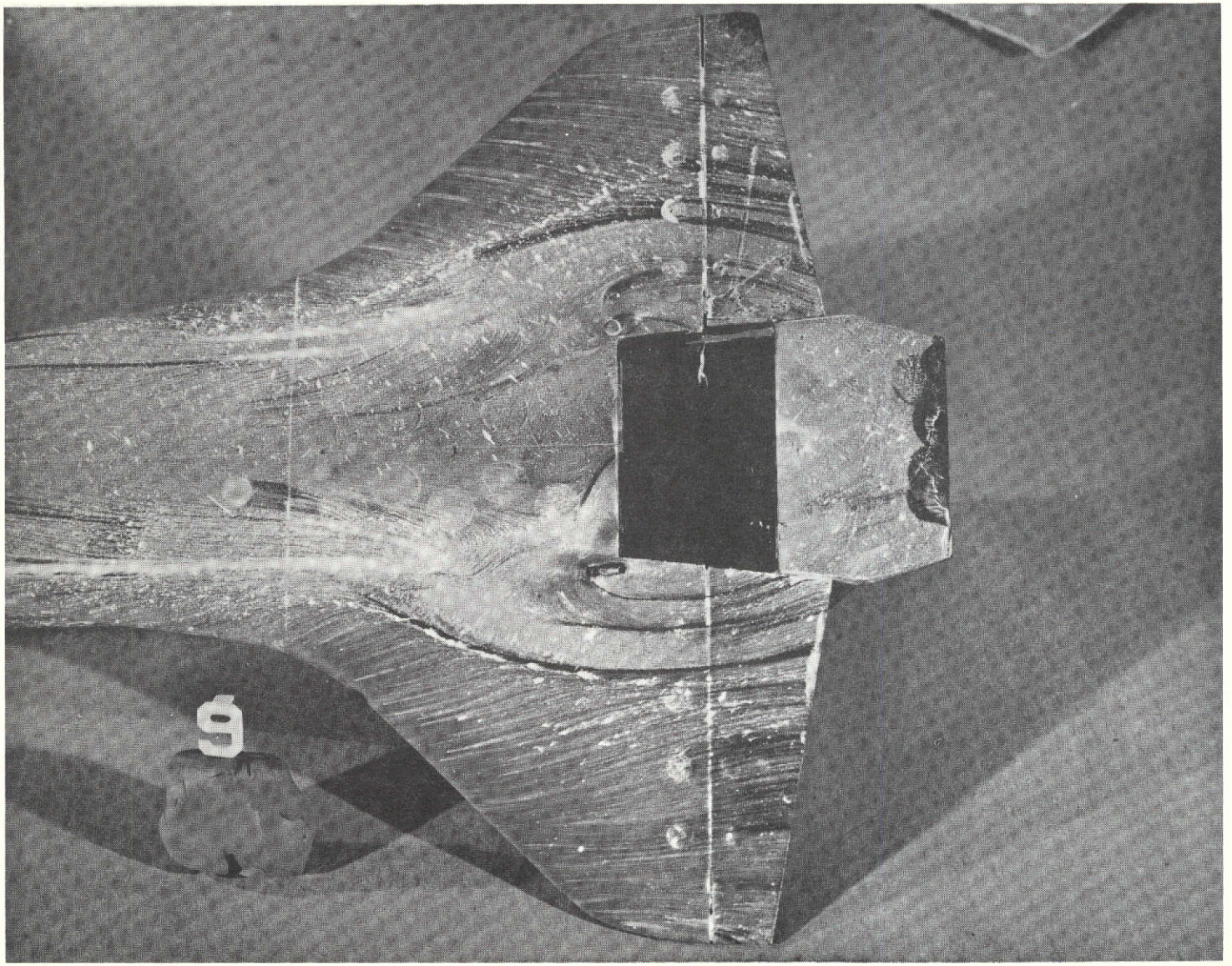


Figure 57. Run Number 9 View Orbiter rear bottom

$\alpha = 5°$, $\beta = 0°$ Configuration Mated

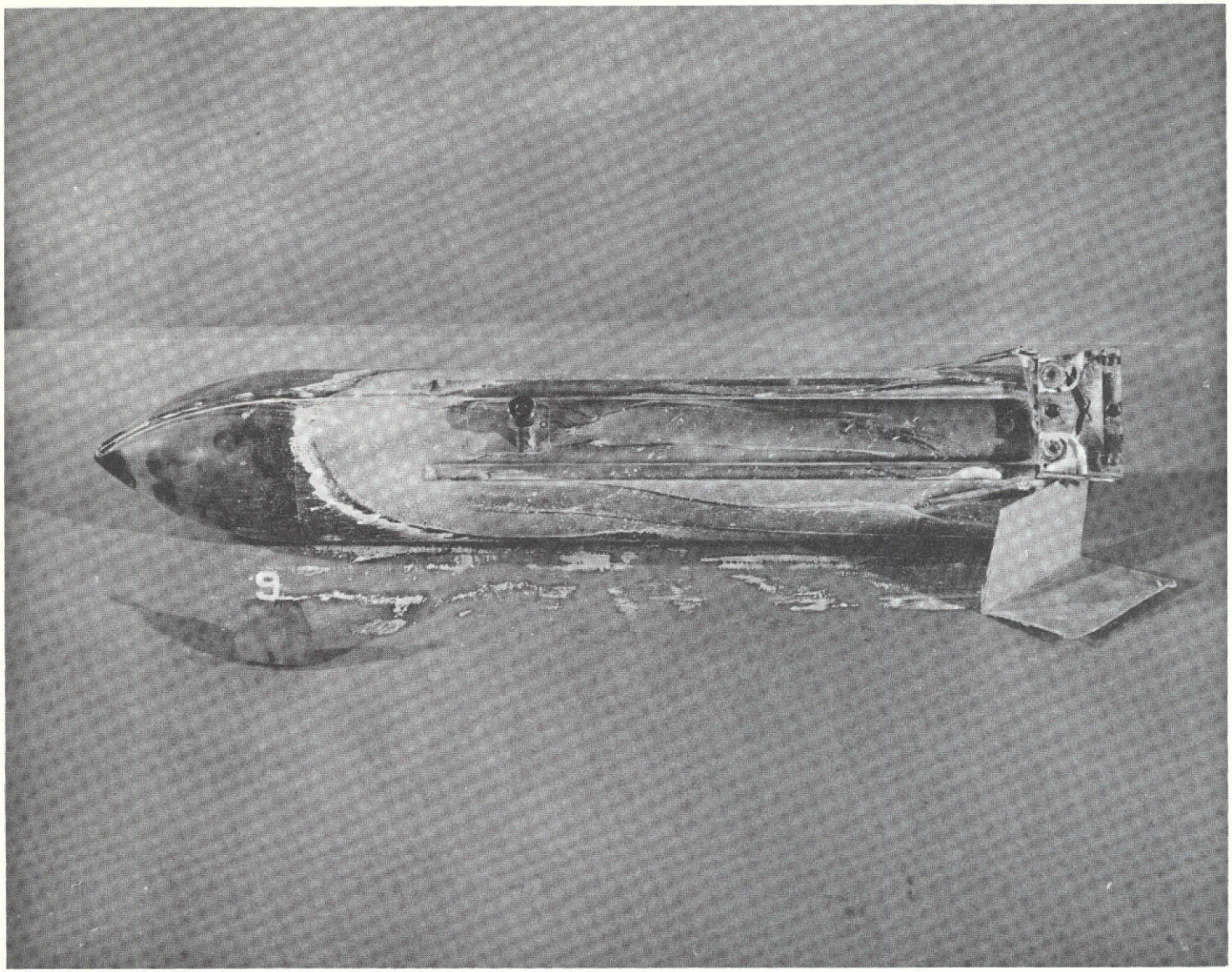


Figure 58. Run Number 9 View Tank top

$\alpha = 5°$, $\beta = 0°$ Configuration Mated

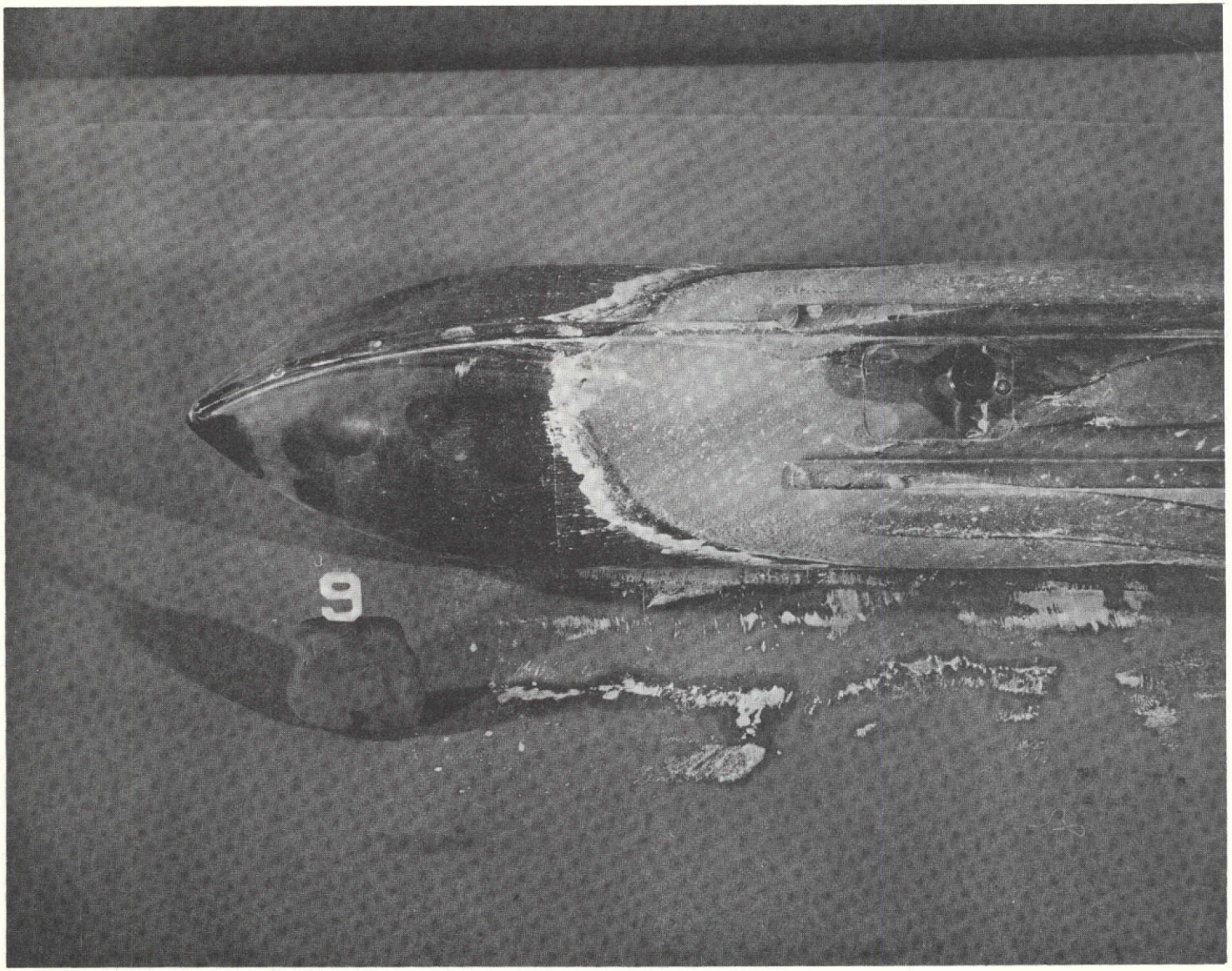


Figure 59. Run Number 9 View Tank forward top

$\alpha = 5°$, $\beta = 0°$ Configuration Mated

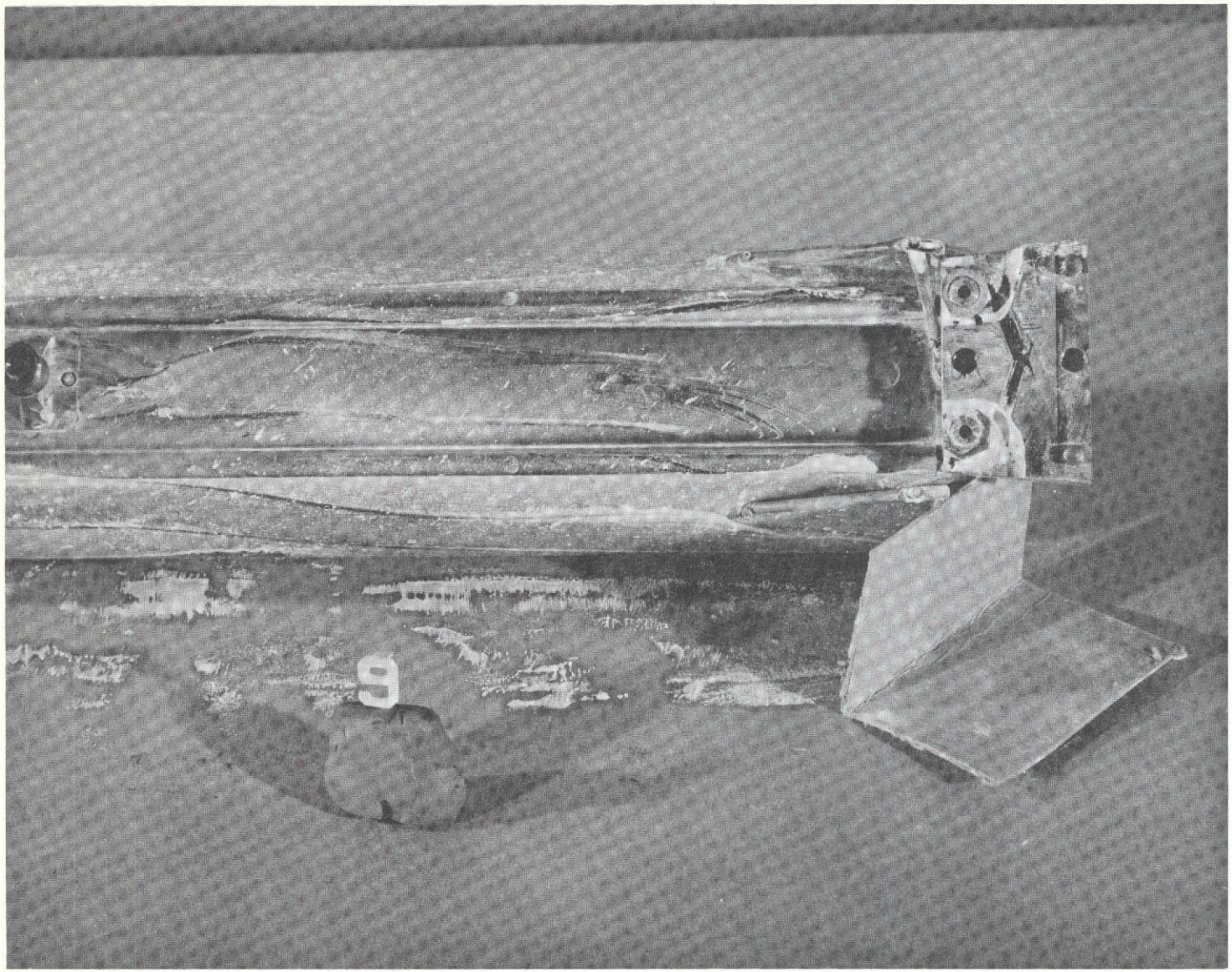


Figure 60. Run Number 9 View Tank rear top

$\alpha = 5°$, $\beta = 0°$ Configuration Mated

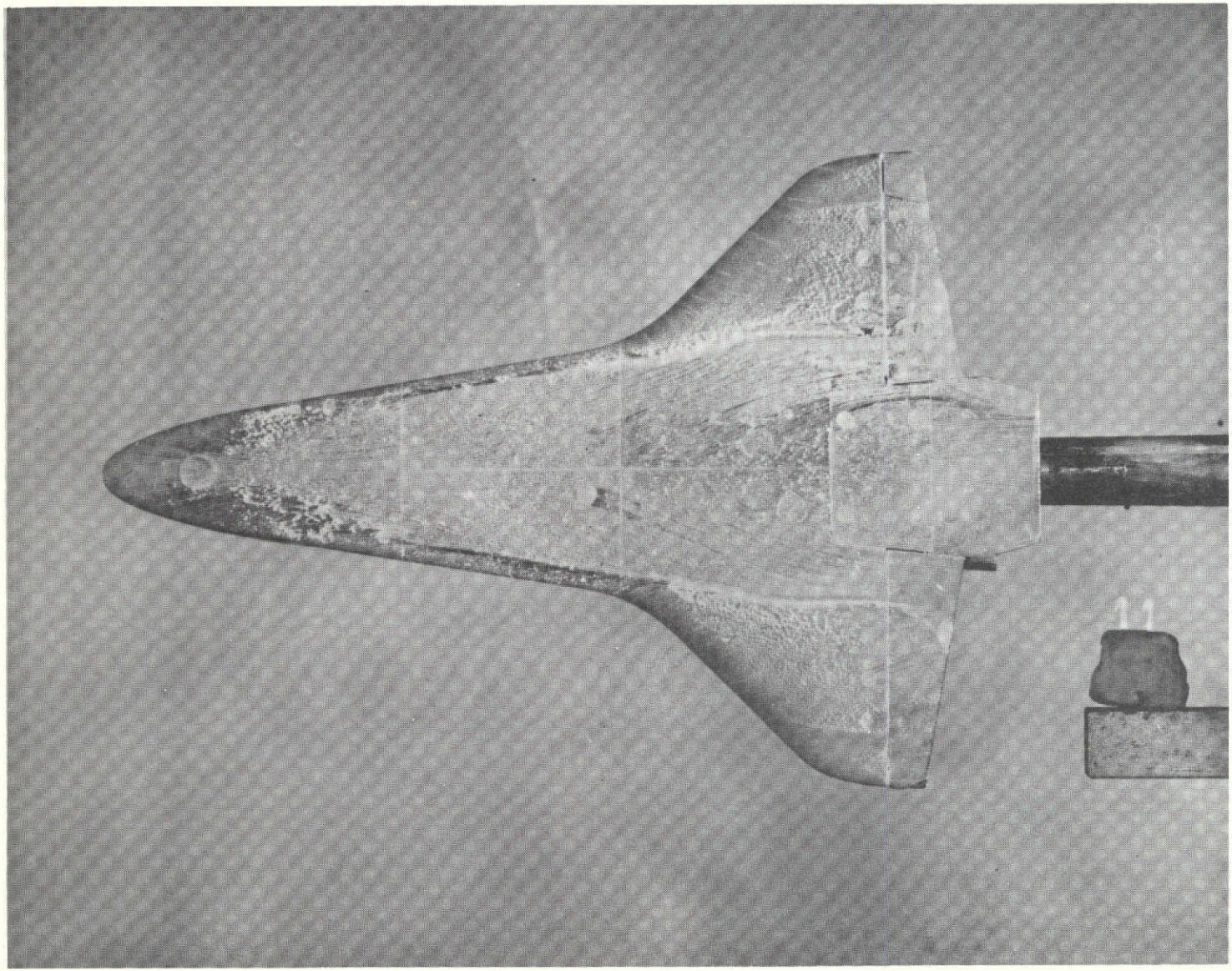


Figure 61. Run Number 11 View Orbiter bottom

α = -5°, β = 0° Configuration Orbiter

C-2

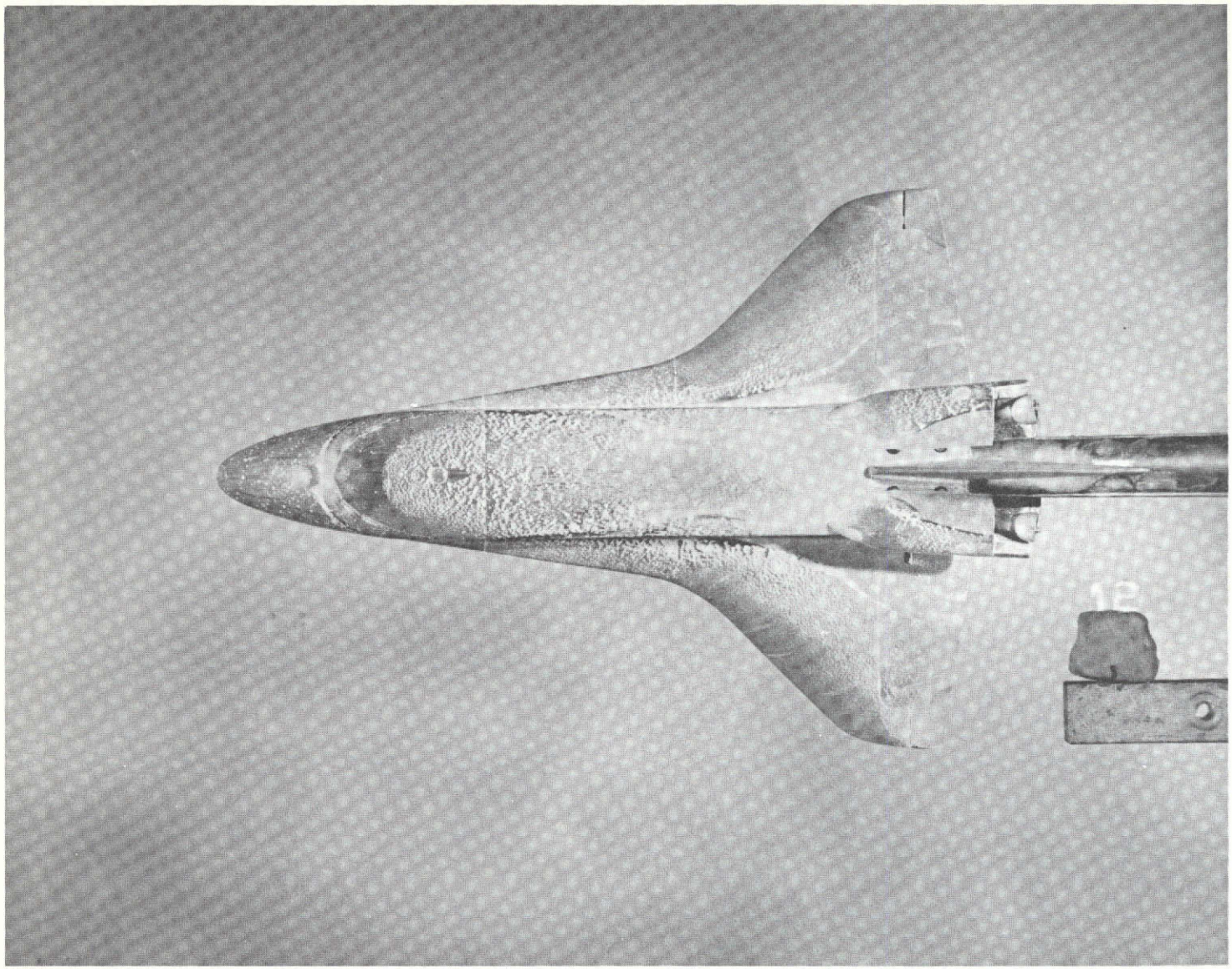


Figure 62. Run Number 12 View Orbiter top

$\alpha = 5°$, $\beta = 0°$ Configuratation Orbiter

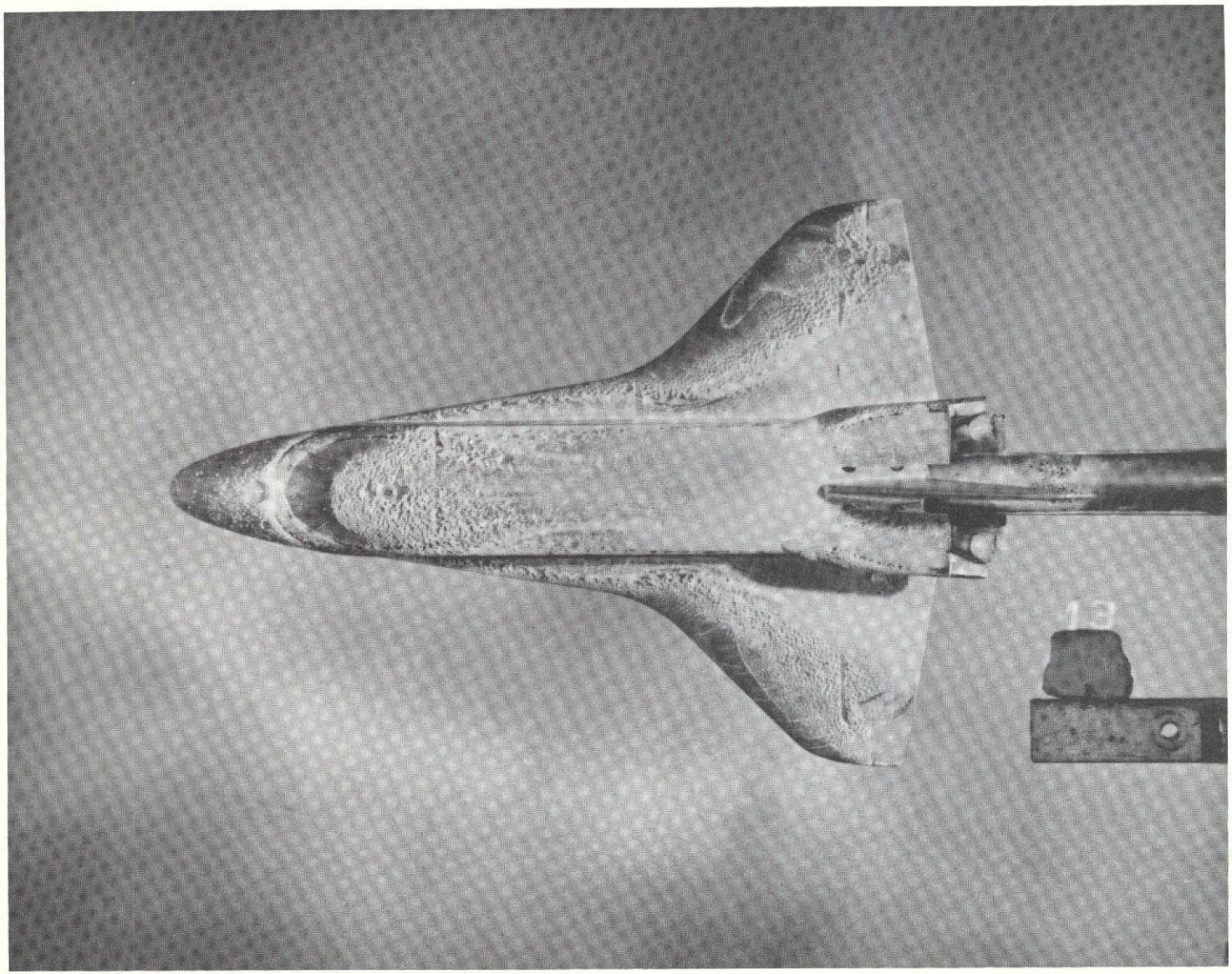


Figure 63. Run Number 13 View Orbiter top

α = 10°, β = 0° Configuration Orbiter